November 2003

SERVO MAGAZINE

The Magazine For Robots, By Robots

Six Legs And Everywhere To Go!

Manage Those Batteries

Ask Mr. Roboto

Build A Brain

Lights, Sound, ACTUATION!

A HISTORY OF ROBOTS IN THE MOVIES

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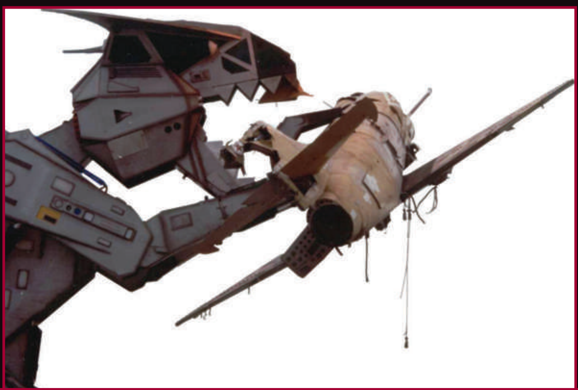

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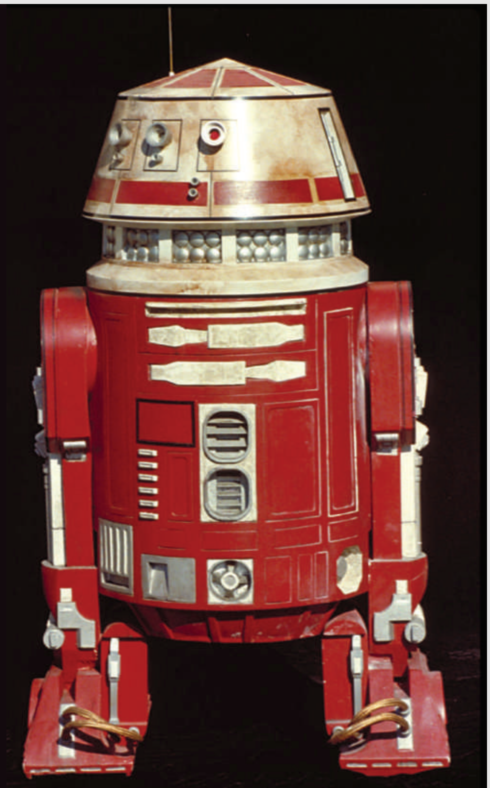

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Mind / Iron

by Dan Danknick

My friend Dave has an Email tagline that makes me laugh every time I read it: "The revolution will be digitized." It is both superficially funny, as well as secretly sublime. As an engineer, I know that once I digitize a sample from the continuum, I can filter, convolve, store, and express it according to my desire. Although I don't have control over the fields of nature, I get to choose how I extract information.

And that is exactly what *SERVO Magazine* is all about — separating raw data from meaning.

Although we started working full-time on this many months ago, the foundation was laid last year when the first *Amateur Robotics Supplement* showed up with the June issue of *Nuts & Volts Magazine*. It wasn't that we produced it — but rather that you, the hobbyist and technologist, consumed it. So like the skips of a stone upon water that grow closer, our publication dates contracted to a monthly interval. And now there are many ripples.

This magazine spans the Gaussian curve, from recreational reading to homework assignment. I expect it to be as much at home on a coffee table as getting splattered with flux remover and tapping fluid on the workbench. I want it to consume your thoughts on the drive home, inspire arguments at your next robotics club meeting, and fill you with the unspoken optimism that technology promises.

I have an A-Team of writers. From Forth evangelists to researchers in cognitive heuristics, there is no facet of robotics that will escape our collective gaze. I am as comfortable publishing the details of CANBUS identifier acceptance registers as I am with Q-learning algorithms and the motion control system in R2D2 (see page 14).

Our currency is ideas. Whether they originate from an electronics inventor in New Zealand, a C++ programmer in high school, or an MIT professor working in the private sector — we are striving to become the Federal Reserve Bank of the robotics movement. Every project presents an obvious benefit in addition to a covert one. We only ask that you show up with a willingness to think.

But if you wish to interact, we welcome that too — check out the Mr. Roboto Q&A column (page 21) and the Menagerie, where you can share your creation with our readership (page 29). The conduit moves information both ways.

And if you act today, you'll even get to choose which side of the A/D converter you wish to be on during the revolution.

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Stars of the Silver Silkscreen

Photo by Giles Westley

ROBOTS WITH CHARACTER. ROBOTS ENHANCED.

by Ed Driscoll, Jr.

The movie industry has long been fascinated with robots, dating back to shortly after the word was coined. In a way, it's not all that surprising given robots' theatrical origin: The word robot was first used in 1920 by Czechoslovakian author Karel Capek, who derived it from robota — a Czech word meaning serf or slave. When Capek's play about the dehumanization of man, *R.U.R.* (short for *Rossum's Universal Robots*), was translated into English, the word robot was quickly absorbed into the English language.

The first movie robot appeared shortly thereafter — "Maria" from Fritz Lang's 1927 epochal film *Metropolis.* If her slender golden shape reminds you of another robot who made his cinematic debut 50 years later, consider the words of Ralph McQuarrie (**www.ralphmcquarrie.com**), the industrial artist George Lucas hired to create the initial illustrations that helped sell *Star Wars* to 20th Century Fox. "George talked about C-3P0 as being a robot that looked similar to the Metropolis robot in Fritz Lang's film. Well, that was a girl, George said, make it a boy." In a way, C-3P0's popularity has helped bolster *Metropolis'* popularity because of the connection between the two robots.

Metropolis' theme of oppressed workers in stifling cities was very much in keeping with many of the concerns of 1920s intellectuals, as communism had only recently become a reality in the Soviet Union, and fascism would soon be on the rise as well. Of course, as David Stork (**http://rii.ricoh.com/~stork**), the author of *Hal's Legacy* (MIT Press, ISBN: 0262692112) has noted, "Science fiction is often about the time it's written, more than the time it's depicting."

(Obviously, as we move forward, we're going to overlook some favorite movie and TV robots in this piece — there just isn't time to go over every robot to clank through a soundstage. But hopefully we won't miss too many of the milestones.)

Robbie: The Man in the Polypropylene Suit

Robots largely took a back seat in the movies until the 1950s, when a variety of forces converged to allow the decade that brought us *The Man In The Gray Flannel Suit* to also bring us men in the oversized molded polypropylene suits, including one of the most famous movie robots: Robbie.

As Peter Abrahamson, (**home.pacbell.net/roninsfx**) the founder of Ronin Special Effects (and a fine robot builder himself) says, "I really enjoy robots that have character, and that's one of the reasons why I love Robbie so much. Because Robbie was great, even though he was a robot, he really had a certain coolness to him. He had a great character about him." Robbie's character is enhanced by the tension created by his somewhat menacing black form and booming mechanical voice, and his initial ambivalence as a character — until the end of the film, it's hard to tell whose side he's on. By the end of *Forbidden Planet,* as he pilots the "United Planets" spacecraft home to Earth, it's clear he's one of the good guys, and well accepted by the crew.

Of course, Robbie requires a certain suspension of disbelief from the audience — his anthropomorphic shape makes it fairly obvious that there's a man inside him. Zack Bieber, owner of The Machine Lab (**www.themachinelab.com**), says that in addition to the limitations of movie special effects, "Robots needed to be human-like to install any kind of emotion in the audience. You know the robot is angry when it bangs its fist into the spaceship, because that's something that a human would do. So to convey that emotion, you had to depict something that the viewer could relate to."

Life Inside a Machine

Perhaps the first great change in what a robot could look like occurred in Stanley Kubrick's 1968 film, *2001: A Space Odyssey*, which to many critics (and fans alike) is not only the greatest science fiction film ever made, but a watershed moment in movie history.

Kubrick wanted to show how man evolved from primitive apes (with a powerful assist from a God-like monolith) to his present form. Kubrick gave his audiences two possible successors to mankind: HAL, a sentient super-computer, and the Nietzsche-inspired "Superman" (no relation to Clark Kent) that Keir Dullea's Dave Bowman character

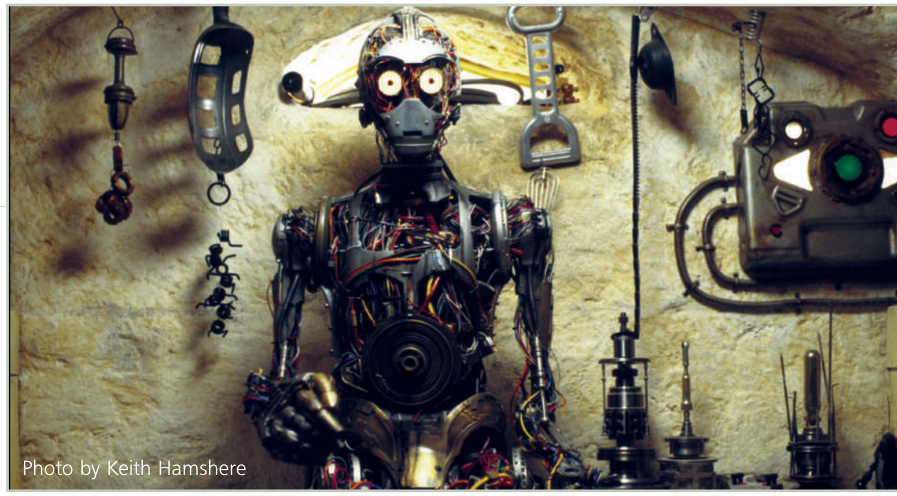


Photo by Keith Hamshere

evolves into at the end of the film.

HAL, who controls the Discovery — the film's main spacecraft — is essentially an intelligent robot that the astronauts live inside of. (In a way, he anticipates the world of The Matrix, where the Earth's entire civilization exists inside a supercomputer.) HAL originally began life as a mobile robot, but given the limits of mid-1960s special effects, and Kubrick's fear that 2001 would resemble previous science fiction films, "I think from a cinematic point of view, it's just far more effective to be enveloped in the computer," David Stork notes, than it is to have it as another actor playing a robot that is alongside the characters onscreen.

Silent Running Through the Empire

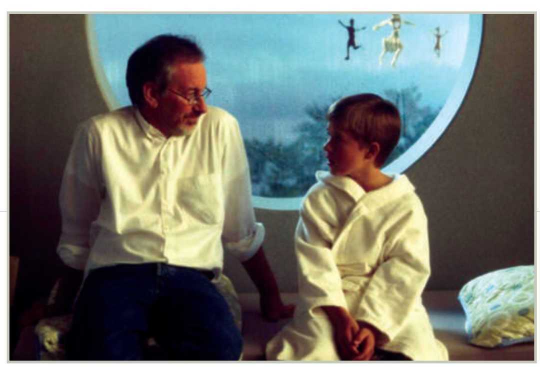
Hal was the springboard for several robots in the 1970s that began to look less and less like men as their shapes diversified. Not coincidentally, this was also the decade that high-tech began to play an increasing role in real life, as robots began showing up on assembly lines, and the personal computer became a reality.

The first big change occurred in 1972's *Silent Running*. As a film, it's aged rather badly — its somber eco-terrorist plot may have seemed hip in the early 1970s, but now feels dangerously realistic. But as a repository for brilliant special effects, *Silent Running* is hard to top. Its three 'drones' — Huey, Dewey, and Louie — were arguably the first movie robots to not look like men in rubber suits.

Of course, that's exactly what they were — Douglas Trumbull, the film's director, hired three actors who had lost their legs, and then designed the plastic costumes around their bodies. Once encased in them, the actors walked on their hands, which were in the rubber and plastic feet of the robot costumes. It's an amazingly realistic effect that holds up quite well.

Silent Running's three drones became the inspiration for one of the most popular movie robots of all time — R2-D2. Along with his companion, the equally famous C-3P0, R2 and he are the non-human glue that holds all of the *Star Wars* films together.

In fact, it's interesting to compare



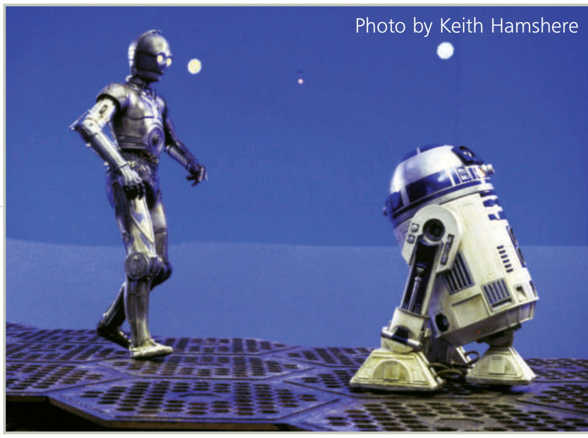


Photo by Keith Hamshere

R2 and C-3P0, and their audience acceptance: the heroic, brave "Artoo," who constantly saves the day in the *Star Wars* films (even getting "killed" and rebuilt at the end of Episode IV) is far more popular than the prissy, cowardly C-3P0, even though C-3P0 has an obviously human shape, and can speak English. And the sprightly Huey, Dewey, and Louie steal *Silent Running* right out from Bruce Dern's morose character.

The 1980s: The Decade of the Android

Inspired by the success of the first *Star Wars* trilogy, the 1980s sparked an explosion of science fiction in the movies and on TV, and with it, came several interesting robotic characters.

In contrast to the non-human robotic stars of the 1970s, the 1980s saw a trend of robots designed to pass for humans. In other words — androids.

In the *Star Wars* films, the word "droid," an abbreviation of android, is used to refer to all of the robots onscreen, no matter what their form. But according to Webster's dictionary, the word "android" dates back even further than the word "robot," to circa 1751, and is based on the Greek word *androeides,* which means, not surprisingly, "manlike."

In the 1980s, man-like androids were featured in the first three *Alien* films, the 1983 cult classic *Blade Runner, The Terminator* films, and on TV, with Mr. Data in *Star Trek: The Next Generation,* who later made the jump to the movies, along with the rest of the *Next Generation* cast.

It's probably not a coincidence that these androids became popular just as the postmodern crowd began asking what exactly man was — did he have a soul? Or was he merely a machine himself?

Of course, fans of movie special effects would argue that these androids began appearing in the movies not because of trendy po-mo philosophizing, but because movie special effects became sophisticated enough to create effects such as the metallic skeleton underneath Arnold Schwarzenegger's *Terminator* character, and the even more impressive liquid metal of the


Photo by Lisa Tomasetti

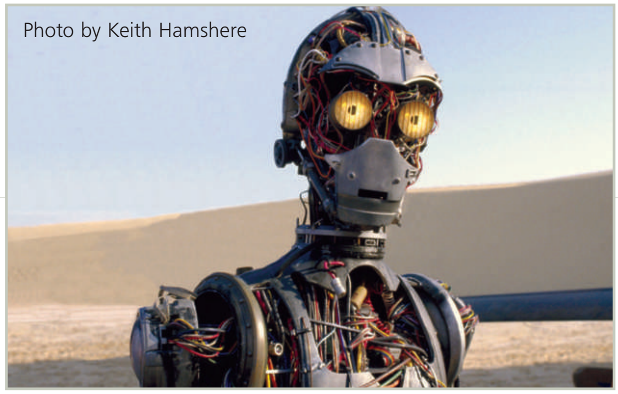


Photo by Keith Hamshere

Photo by Sue Adler

shape shifting terminators played by Robert Patrick in *T2* and the beautiful Kristanna Loken in *T3.*

Perhaps the most beloved android is *Star Trek: The Next Generation's* Mr. Data who, like HAL, is an intelligent, sentient machine. But unlike HAL and the *Terminator* robots who apparently feel they are superior beings, Data, like Pinocchio, wants to be human. At first glance, Data's Pinocchio-like quest appears to be a *Blade Runner* homage. But David Gerrold (**www.gerrold.com**), the science fiction author who created the much-loved tribbles for the original *Star Trek,* and helped develop *The Next Generation,* says that "The most likely antecedent was Gene's show, *The Questor Tapes,*" a failed TV pilot written by *Star Trek's* creator Gene Roddenberry in the mid-1970s.

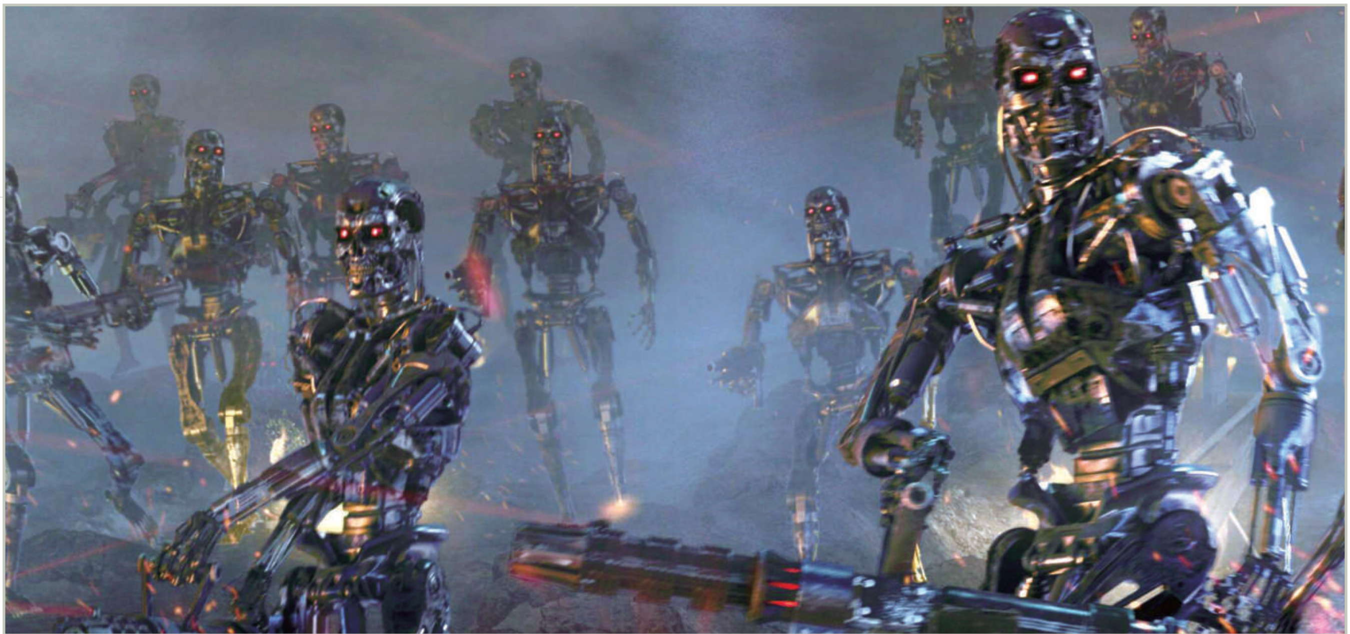
Gerrold, who has two books, *The Man Who Folded Himself* and *The Martian Child* (both recently released in trade paperback) says, "We wanted a character who would take on the responsibilities of Spock, but we didn't want another Vulcan. So we decided to do the opposite of Spock-an android who would be like Pinocchio. He wants to become a 'real boy.' Gene came up with the name Data, despite the fact that just about everybody else hated it."

Fortunately, the audience didn't seem to mind Data's name. And like Spock, because Data allows us to see mankind from an outsider's viewpoint, Data became a science fiction superstar — even if he never did quite become a man.

The 1990s: Is Life But a Dream?

The postmodernists of the 1980s debated "what is man" with android characters like Data. Movie postmodernists of the 1990s could argue, "what is reality?" because by the late 1990s, digital special effects radically changed the scope of what movies could present.

The Matrix trilogy takes *2001's* theme of living in a spaceship controlled by a computer to its ultimate conclusion: What if your very existence is an illusion created by a computer? The result is a wild ride, as inside the Matrix, the human characters such as Neo, Morpheus, and Trinity fight holographic androids in the form of Agent Smith and his cohorts. And outside the Matrix, our intrepid trio fights the evil-look-



ing robotic Sentinels. All of which are controlled by a central computer, which uses humans as "living batteries." (Or at least that's what we know from the first two movies. The last film in the trilogy, *Matrix Revolutions,* hasn't been released at the time this article is being written, and promises additional mind-blowing plot twists.)

The Evolution Continues

Based on a concept developed by Stanley Kubrick, Steven Spielberg's *A.I.* is a maddeningly inconsistent film, but it shows a world in which robots are evolving far faster than man is. David, the Pinocchio-like boy played by the charismatic young actor Haley Joel Osment, is years beyond our current technology. But by the end of the film, he meets up with even more advanced robots, which control planet Earth thousands of years in the future, after mankind is extinct. Of course, our current level of technology is nowhere near David, Hal, R2, or the Matrix (I think ... say, who was that fellow in the black suit and tie clip following me last night??) But robots, as this new magazine demonstrates, are increasingly all around us. And artificial intelligence will be a reality as well — someday. But as David Stork notes, "It's going to be many, many decades. Or as John McCarthy said, it will either be within four, or four hundred years, and it depends on getting two Einsteins and three Von Neumanns-you can't predict it; it could be soon, or might not be."

In any case, the movies have given us a wonderful sneak preview into our biomechanical future.

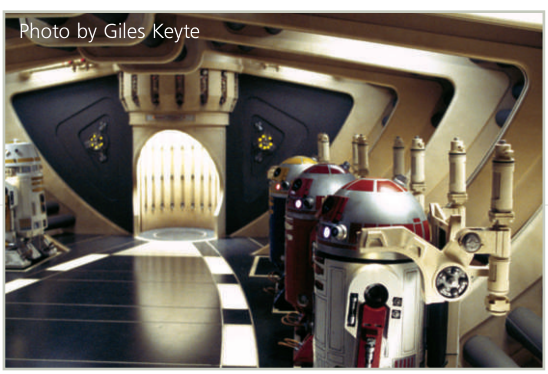


Photo by Giles Keyte

Inside The World's Most Popular Droid

"Hey, this R2 unit of your seems a bit beat up. Do you want a new one?"

"Not on your life! That little droid and I have been through a lot together."

R2-D2 is such a popular movie robot, and so beloved by many readers of *Nuts & Volts* and *Servo*, that we wanted to interview the man who controls him, to find out exactly what's going on underneath R2's silver and blue dome.

Don Bies (**www.starwars.com/bio/donbies.html**) began with Industrial Light and Magic in 1987 as a puppeteer on The *Witches of Eastwick,* and later that year joined Lucasfilm Ltd., as R2-D2's operator for a series of Japanese commercials. Since then, he's controlled R2 on each of the latest trilogy of *Star Wars* films, including its final chapter (apparently titled, if you believe the Internet rumors, *Star Wars: Episode III: An Empire Divided,* which obviously is subject to change), due for release in May of 2005. As he's in Australia, shooting that film's live action sequences, we spoke with Bies by phone.

Bies says that mechanically, R2 is actually quite simple. "We've got two wheelchair motors in the left and right foot. And then the front foot is a caster. For the head turn, we just directly attached a big chunky servo, and it works pretty well."

Ever since Episode I, Bies has used Futaba 9ZAP nine channel model airplane radio control units to operate R2. Essentially stock, their batteries have been replaced by Makita batteries for longer life.

"We have a Vantec speed control (**www.vantec.com**) to control the motors. It drives off of one stick, and it's done through the Futaba radio transmitter. So I can just push this one stick forward and the robot runs forward. And if I push it backward, it goes back, and left goes left, and right goes right, as opposed to having two stick controls, as in a tank drive."

Back to the Future

While the current *Stars Wars* trilogy features gobs of cutting-edge digital technology, much of its production design owes its lineage to the first round of *Star*

Wars films, back when movie special effects were far less sophisticated.

While R2's basic shape came from the seminal illustrations that George Lucas had painted by industrial artist Ralph McQuarrie, his design was finalized by John Stears, who headed the British on-stage special effects department of *Star Wars'* original soundstage — EMI's Elstree studios.

The many documentaries made during the shooting of those first *Star Wars* films featured numerous shots of radio controlled R2s crashing into walls, or simply refusing to move on cue. Bies admits that the original R2s "had a lot of problems, because the R/C technology at the time was pretty much in its infancy. But since then, the radio control units themselves have become very, very stable."

The stability of those controls allows Bies to effectively think like an actor when he's on set, "to a certain extent. I don't want to sound like I'm doing brain surgery or anything," because R2 is "so limited in what it can do — the head can turn, and we have the little holographic eye that moves up and down, so you can get a little motion out of that. I think that 90 percent of R2's character comes out of the sounds that they put in later, so you get all those movements in with the bleep or the sad whistle or whatever."

The Man Inside Artoo

Of course, R2 has another handler — since the mid-1970s, three foot, eight inch tall Kenny Baker (**www.kennybaker.co.uk**) has often been inside of him. In the original films, in most shots where R2 was shown waddling on two legs, Baker was inside. For George Lucas and the rest of the original *Star Wars* production team, having an actor inside of Artoo was often far more reliable than the R/C controls of the time.

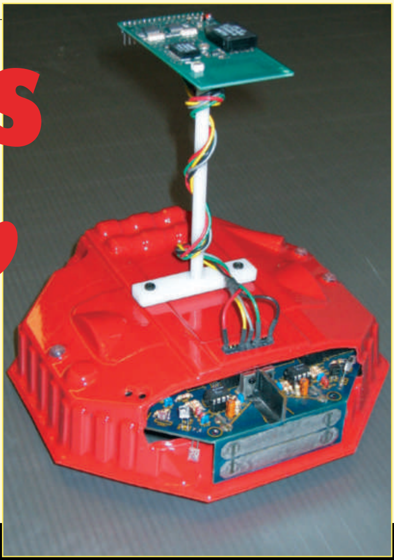
For better or worse, technology has rendered Baker increasingly superfluous to the latest trilogy. "Kenny's been used less and less," according to Bies, "partially because of the stability and the reliability of the R2 units, and partially because R2 is going more in the digital route. In *Episode I,* Kenny was in the film a fair amount, whenever there's a two-legged version. In *Episode II,* we didn't use Kenny at all in Australia — we were able to do everything with the radio-controlled units. And if we needed a two-legged R2 for a shot, it would typically be me just hiding behind, or underneath it wiggling it around when necessary, with a radio-controlled head that we put on it, so that it could turn its head back and forth."

Bies says that it was out of courtesy to Baker that Lucas allowed him to control R2 for one shot in *Episode II.* And Bies is sure Baker will be inside R2 for a shot or two in *Episode III,* as well. The films just wouldn't look right without Baker getting a screen credit for portraying R2.

And digital effects are reducing Bies's role with R2, as well. "On *Episode II,* somebody did a shot count, and there were something like 96 R2 shots in the film, and 14 of them were digital R2s, there was one Kenny shot, and then the rest were me with the radio controlled units. With *Episode III,* it's too early to tell, but R2 has a bigger role in the film, and has more action sequences, so there will probably end up being more digital shots of R2 in the picture."

Of course, whether he's radio controlled, actor controlled, or digital, R2 will always be a hero to movie fans.

Power Challenges In "Always On" Robotics



by Roger Gilbertson

Introduction

Science fiction stories have always set the standards for what people expect from "real" robotic creations. Books and movies like *I, Robot*, *Silent Running*, and *Short Circuit* portray robots that exhibit intelligence, resourcefulness, autonomy, self-preservation and other sophisticated behaviors.

Consider the famous odd couple from the *Star Wars* series — R2-D2 and C-3PO. They navigate their environments, communicate with each other, and plan rescues of themselves and their human counterparts. Even though we find these fantasy robots captivating and compelling, their high level abilities do not exist in present day robots, but remain the exclusive domain of "living systems."

Witness the long and thus-far fruitless efforts to create true "artificial intelligence." Even "Deep Blue," IBM's specialized chess playing computer which soundly defeated human chess champ Garry Kasparov in 1997, has nothing near the abilities of the fictional HAL 9000 computer in the classic motion picture *2001: A Space Odyssey.*

The many assumptions — both stated and unstated — that lurk behind science fiction robots provide robot builders with many daunting challenges. Consider the issue of power.

Power Challenge

In the classic TV series *Lost In Space*, robot B-9 had its own station aboard the Jupiter 2 spaceship and regularly returned there for recharging.

Likewise, R2-D2 never exhibited a "low battery" condition in the middle of a battle, or at any other time. The plucky little Astromech droid routinely located and accessed information ports conveniently placed throughout the Death Star and other Empire facilities. Though never directly explained in the movie, droids like R2 evidently could also recharge themselves as needed, without human intervention.

So the challenge that we as robot builders face in trying to "make the future come true" lies in bridging the gap between our imagination and what we can successfully build.

To understand that challenge, picture a simple modern robot capable of "living" around your home. Assume it can run for six hours on a set of four AA batteries. Operating 24 hours a day, 7 days a week, and using regular alkaline cells, it would need a total of 5,840 batteries per year!

If the same robot used rechargeable batteries (a big cost savings, for sure) at four battery changes a day, you would perform 1,460 swaps per year — more than the number of meals you'll consume in the same time. With the robot requiring this kind of attention, you'd have to wonder who's the servant and who's the master!

So to significantly reduce the amount of "routine" attention a robot requires from humans, our mission lies in finding ways to endow the robot with the ability to reliably care for its own power needs.

Four Paths to Robot Power

Let's step back and take a look at the four general ways that autonomous robots handle their needs for power here at the start of the 21st century.

Path 1 — Live Fast, Die Young

Robots on this path use power at whatever rate they need, but they neither sense nor "worry" about their reserves running out. When the batteries ultimately do die, so do the robots.

Most small and "toy" type robots use this approach. They generally can continue operating even as their power levels drop, though they may move more slowly as this happens.

Path 2 — Spend What You Earn

These more frugal types of robots carry solar cells to charge a storage device, then when they have gathered sufficient reserves they move, sometimes just in small jumps. Of course, when the sun or other light source stops shining, the

robots stop too. When the light returns, they continue.

Solar powered B.E.A.M.-type robots use this approach to great success, but power availability generally limits their size, since larger robots usually need more power. (All other fac remaining equal, as robot size increases the mass goes up by the third power, but solar panel area increases only by the second power.)

Over the past 10 years, Sweden's major appliance company — Husqvarna — has fielded several models of solar powered lawn mowers to generally positive reviews. Resembling large beetles, the mowers exhibit flat top surfaces covered in solar cells, and undersides with small whirling blades that continuously nibble at the lawn as they careen randomly around the yard. A "perimeter wire" emitting a faint radio signal limits their zone of operation.

Path 3 — Do Your Thing, Then Call 911

As this kind of robot loses its charge, falling power levels can dramatically affect its performance, causing slowed motions, delayed responses, and endangering its circuitry, its memory, and even nearby life forms.

To protect the robot itself from dangerous "brown out" conditions, as well as anything in the nearby environment (including robot inventors) from spastic or intermittent behaviors, microprocessor controlled circuits often include low-voltage detectors that shut the machine down before processing errors can occur.

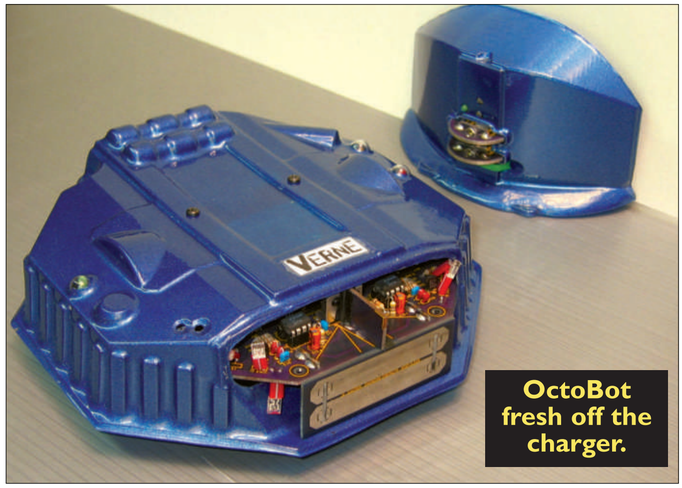
All Path 3 robots monitor their own power levels, and then modify their behaviors to conserve energy, compensate for slowed motors, etc. When voltages become too low to operate properly, the robot may sound an alert, light an LED, or ask for assistance in some other way. Then, a human must step in and either provide power or return the robot to an appropriate charging station.

Many "home and garden" robots such as vacuum cleaners and lawn mowers indicate their power levels via colored LEDs. Then they "rely on the kindness of strangers" to assist in their recharging process.

While this kind of robot offers better performance than those having no means to compensate for declining power reserves, a robot that monitors its own power levels still depends on a human being in the life support cycle. Nonetheless, such robots have some awareness of their own condition, and that puts them just a step away from autonomously caring for their own needs.

Path 4 — Robot Feed Thyself!

When a living creature gets hungry, it seeks out food. Plants turn towards light, and large creatures eat smaller ones. All living creatures survive due to this essential ability to sense their own low energy and find sources to replenish their reserves. Since an autonomous robot already has the ability to navigate through its world, why should it not also seek out and acquire its own power? It seems like a small jump, but in the past, too few robots have attempted to do just this. One can't help but wonder if more of the early robots had incorporated this ability that they might still be on duty today.



OctoBot fresh off the charger.

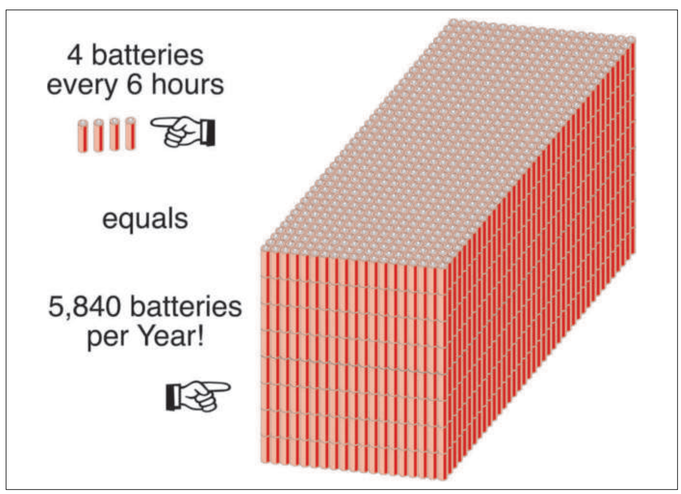
Unfortunately, only a very small percentage of contemporary robots have the ability to tend to their own recharging. Some home, entertainment, and garden robots can, but they all carry prices well over $1,000.00. High performance seems to carry a high price.

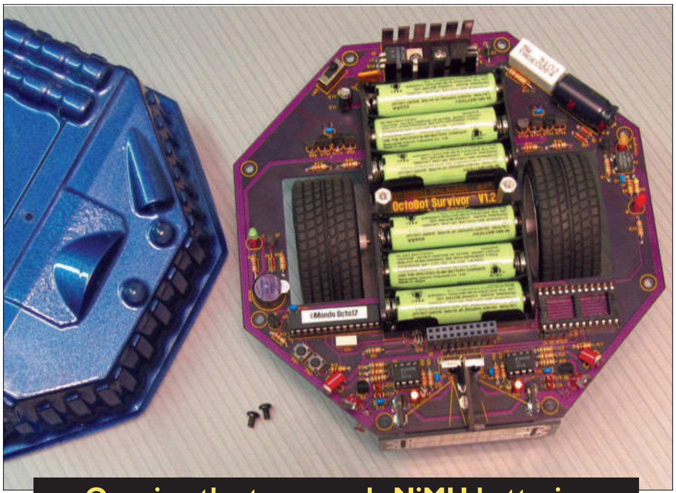
Given the low cost of powerful microprocessors, and the wide availability of functional robot platforms, how can we create a self-charging robot system priced within reach of hobbyists and experimenters?

This observation prompted my associates and I to develop and produce the OctoBot Survivor, the first self-recharging robot kit for hobbyists and experimenters priced at under $200.00.

The OctoBot Survivor Story

Starting in the fall of 2002, the design team from Mondo-tronics and I began exploring the options available for building a self-charging robot so that students, hobbyists, and experimenters could begin testing the boundaries of self-charging robots. For convenience and familiarity, we started our project with many parts literally "off the shelf" from our **RobotStore.com** warehouse. Items such as the Twin Motor Gearbox and wide rubber tires from Tamiya, the Mini Dual H-bridge Driver Circuit, the Infrared Proximity Detector circuit, and others proved handy in creating work-





Opening the top reveals NiMH batteries (green) and 20-pin expansion header.

ing prototypes to test our initial concepts.

Once we had a basic system working, our long time collaborator and experimenter extraordinaire, Zach Radding, began writing the software routines. The outline for the brain's function went as follows:

On a full charge, the OctoBot will select one of two modes: phototropic mode (active / "happy"), or photophobic (not as active / "sad"). On a battery low condition, the OctoBot will seek the charging station, stop when it makes contact with the station, and leave the station when the batteries are charged.

Initially, the design called for two LEDs as the only output indicators, but Zach pushed for the addition of a small speaker as a way to "bring a little more life into the bot." We agreed to that, as long as the noises sounded pleasant rather than annoying.

During the "happy" and "sad" modes, we wanted the robot to exhibit a variety of behaviors such as object avoidance, light seeking, dark seeking, wall following, and random wandering. Zach created routines for making "emotive" tones that indicate the general state of the robot (without being annoying).

A PIC 16F876 microprocessor serves as the brain of the OctoBot. The robot carries six AA-size nickel metal hydride (NiMH) cells and the Dallas Semiconductor DS2436 — a compact battery charging-and-monitoring circuit. Another long time associate, Ed Severinghaus, contributed the designs for the battery charging system, and related power systems.

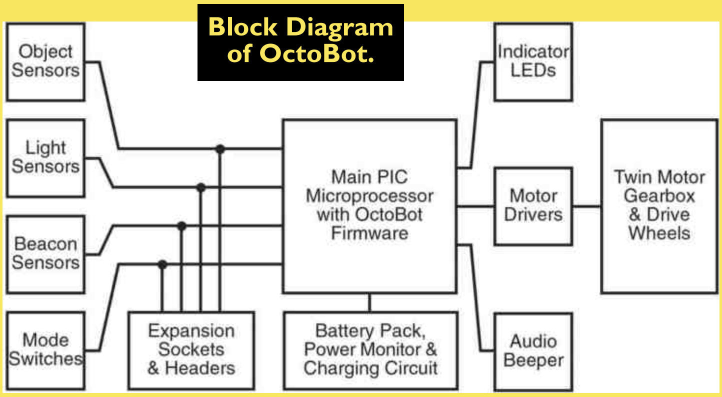
Once we worked out and tested the circuits, I began the layout of the main circuit board and many smaller supporting boards, and prepared the documentation and related materials.

Creature Features

As hobbyists ourselves, we wanted to include a great deal of expandability into the OctoBot. First of all, we added a 24-pin DIP socket for a Stamp 2 processor and included connections from it to all of the sensors, and a direct line to the OctoBot's PIC brain. On start up, the PIC briefly "listens" to the socket, and if a Stamp responds, the PIC defers to the Stamp for commands. In this mode, the PIC remains very active, performing "low level" tasks such as movements, seeking the charger, reporting on the battery condition and such, thus freeing up the Stamp program for bigger tasks.

The OctoBot also has two expansion ports to support user-added circuitry. A 20-pin header rests at the center of the robot, and follows the Stamp Expansion Header format from Parallax, Inc., makers of the BASIC Stamp processors. This header gives easy access to all the sensor signals and the PIC processor, so that add-on boards can take control (in the same way as the Stamp 2 socket), or can carry out other functions.

The second, smaller expansion port on the bottom side provides power, ground, and four of the unassigned input/output lines. This port makes it easy to add circuits for line following, edge detection, shaft encoders, and more. For our own development purposes, we first added an LCD display to the 20-pin header, so that our programs could report on their conditions. We've since added RF modems, sonar boards, and a variety of other sensors. These projects may make their way into future articles.



Block Diagram of OctoBot.

OctoBot Challenges

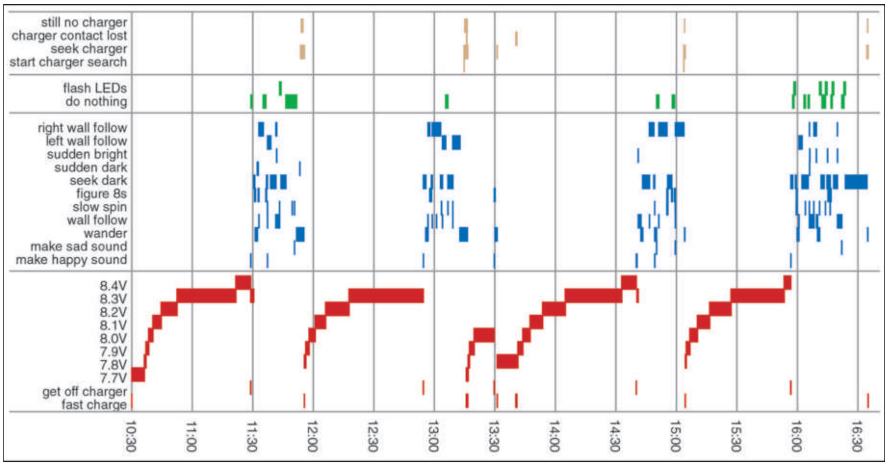
Just as a fish finds itself well-adapted for life in water, but operates poorly on land, a robot's features and abilities must also match its intended environment.

The OctoBot lives best in a fairly "safe" environment — with clearly visible walls, no sudden drop-offs, no water hazards or sand traps, and no narrow objects like chair legs. But the OctoBot welcomes other obstacles in its environment. The IR proximity sensors can detect nearly anything that reflects infrared light — cardboard boxes, wood blocks, sheets of paper, shoes — and experimenters can build their own complex and interesting environments for their OctoBot, including light sources, areas of dark (caves for when exhibiting photophobic behav-

iors), and more.

Also, two or more OctoBots may even inhabit the same space, since they can easily detect the protective body shells of other OctoBots. However, interesting results can occur if two OctoBots become hungry at the same time and attempt to share the same charger. (Darwinism may take over and only the fittest survive!)

If, for whatever reason, an OctoBot should find itself running so low on power that it cannot make it to a charging station, it will end up "calling for help" by repeatedly uttering its startup tones. If not rescued by a human at some point, it will eventually become too weak to even speak, and shut down until a human transports its lifeless shell back to a charging station. Then, resurrected by a fresh charge, it will continue with its existence, unimpaired by the experience.



Six hours in the life of OctoBot.

OctoBot Choices

Unlike some of the more sophisticated self-charging robots, the OctoBot contains no internal representation of the world, and no map or knowledge of its surroundings — it does not even store its "mood" but references that "emotion" directly from its battery voltage level. Likewise, the OctoBot need not perform any path planning or calculations in order to return to its charger. Instead, it simply wanders in search of the charger's IR beacon (using its reflexive responses to avoid walls and obstacles along the way). Once located, it moves toward the beacon until it makes contact with the charger contacts. Then the on-board charging system monitors the batteries until fully charged (from one to three hours).

In designing the OctoBot system, we observed some interesting tradeoffs between various design choices. One situation involves the interplay between the light output level of the IR beacon emitters, the abilities of the robot's beacon detectors, and the nature of objects in the environment. In some cases, these three factors can combine to mislead the robot. Specifically, a brighter IR beacon may allow the OctoBot to find it from farther away, but it also sends light bouncing around to more places (IR reflects very easily). In a darkened room, the robot can end up searching for the beacon as if wandering in a house of mirrors — following false reflections away from the charger, and eventually dying a slow death chasing the "ghosts" of the beacon.

Another design interplay comes in setting the reserve level of the robot's battery pack. An OctoBot that never ventures too far from its charger beacon (for example, if it lives in a smallish enclosure) would generally need little reserve power in order to drive itself back to the charger. However, an OctoBot living in a larger enclosure may require much more power in order to successfully locate the charger and return to it from farther away. So the question becomes, at what voltage should the robot begin searching for the charger?

In the end, we chose a reserve level in the middle of the range — high enough that the OctoBot should have good reserves to return from a fair distance away (the beacon detection system works to about three meters away), yet low enough that the robot does not constantly feel the need to feed.

A Day in the Life of "Asimov"

So what does an OctoBot do with its time? For the purposes of this article, I enlisted "Asimov," one of our oldest and most experienced OctoBots, and attached an RF radio link to it so it could wirelessly report its status to a nearby PC with an RF receiver. (This might also find its way as the subject of a future article).

In this way, we recorded all the OctoBot's actions for a day or so, and then analyzed the results. The pie chart gives a summary account of a typical six hour period of its day.

Note how Asimov spends about two thirds of its time charging (red). Nearly one third of its time involves doing various robot tasks around its enclosure (blue), or sitting quietly and blinking its LEDs (green). Notice how little time it actually spends in searching for the charger station (tan) — about one percent. These results indicate that Asimov would probably perform well in a larger enclosure with more obstacles, which would make for more interesting behaviors while wandering, light and dark seeking, etc. This would result in more challenging charger searches.

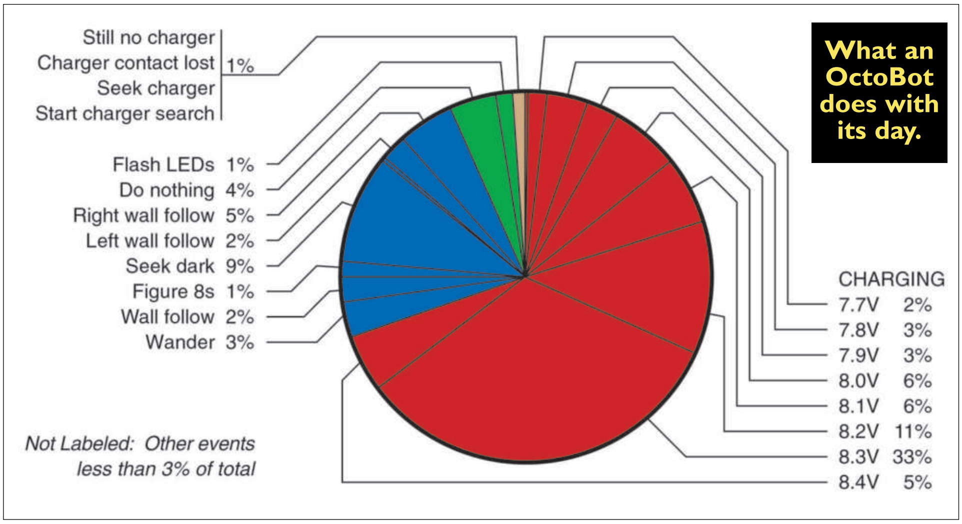
A Self-Charging Future?

The OctoBot Survivor kit gives hobbyists and experi-

F.Y.I.

About the Author

In college Roger G. Gilbertson studied engineering, robotics and the walking patterns of living creatures. In 1987, he co-founded Mondo-tronics, Inc. to explore the commercial applications of Shape Memory Alloy wires, and in 1995 launched RobotStore.com, the internet's first commercial robotics site. Mondo-tronics' Robot Store continues to lead the field in presenting the best and most innovative new robot products for students, educators, hobbyists and experimenters. Roger lives and works in Marin County, California, where an intelligent android has not yet managed to get placed on the ballot for Governor.



menters the keys to unlock doors that lead to greater realms of robot autonomy. We see many more directions to explore with the OctoBot Survivor and its kin — developing better navigational methods, expanding its range and endurance, increasing its ability to survive in more varied environments, and perhaps some day even the ability to operate outdoors in more complex "real world" environments.

For technical information on the OctoBot Survivor Robot kit, including assembly instructions, accessories, examples of BASIC Stamp 2 code and more, please visit our web site at **RobotStore.com**

Conclusion

Every new technology presents us with opportunities to make our world both safer, cleaner, and more productive, but also more complicated and even more dangerous.

As the builders of the future, we carry the great obligation to our descendants to create the best that we possibly can, and to prepare ourselves for the inevitable changes that accompany every technological shift.

The challenges of creating robots that care for their own basic needs will continue to daunt us for many years. However, by following our science fiction dreams, and by developing our own clear visions of what we want (and do not want) to achieve, students, hobbyists, and experimenters of all levels can make significant contributions to this exciting frontier. In time, our creations themselves may turn to us and say, "Thanks!" Build more robots!

ASK MR. ROBOTO

by Pete Miles

Tap into the sum of *all human knowledge* and get your questions answered here! From software algorithms to material selection, Mr. Roboto strives to meet you where you are. And what more would you expect from a complex service droid?

roboto@servomagazine.com
Our resident expert on all things robotic, is merely an Email away.

Q. I want to build a robot with big wheels in the back and smaller ones in the front. But I want each side to be driven by the same output shaft from my gearbox. Obviously, I need to drive the larger wheel slower than the smaller one to keep the linear speed the same. How do I compute the sprocket ratios for each? I am going to use #25 chain.

— Anonymous via Internet

A. You are correct about having to drive the larger wheel with a lower RPM than the smaller wheel. The short answer to your question is that the sprocket ratio must be exactly the same as the wheel ratio, and the large sprocket must be mounted on the large wheel. The #25 chain doesn't really come into this decision process unless the torque loads on the chain can cause the chain to break, or weight becomes too excessive.

The long answer in calculating the sprocket ratios for the wheels begins by calculating the ratios of the two wheel speeds, as a function of the two wheel diameters. Figure 1 shows a simplified sketch of this type of configuration. The linear velocity of the wheels is shown in Equation 1, where N is the rotational speed in RPM and D is the diameter of the wheel.

Since both of the wheels are rolling on the same surface, their linear velocity will be equal (as shown in Equation 2). Equation 3 shows how the wheel ratio affects the larger wheel's speed as a function of the smaller wheel's speed. Since D1 is larger than D2, the rotational speed of the larger wheel, N1, must be slower than the smaller one, N2, which is in agreement with your question.

To calculate the sprocket ratios, the same type of an analysis is conducted. Instead of the ground connecting the wheel speeds together, a chain is used to couple the sprocket speeds together.

$$v = \pi N D$$

Equation 1

$$v = \pi N_1 D_1 = \pi N_2 D_2$$

Equation 2

$$N_1 = \frac{D_2}{D_1} N_2$$

Equation 3

Equation 4 shows how the sprocket diameter ratios relate to the rotational speed of the sprockets. Here, the sprocket diameters are shown with the letter S.

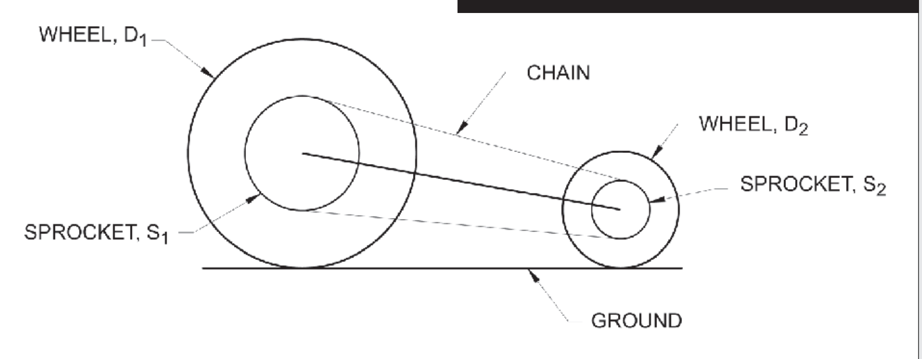
$$N_1 = \frac{S_2}{S_1} N_2$$

Equation 4

Since the sprockets are physically attached to the same drive shaft as the wheel, the sprocket ratios can be equated to the wheel diameter ratios as seen in Equation 5.

For this type of a robot drive system to work properly, the sprocket ratio must be the same as the wheel ratio. Sprockets are usually identified by the number of teeth they have instead of their actual diameters, so the letter S can be substituted with the number of teeth on the sprocket. The ratio will be based upon the number of teeth on each of the sprockets.

Figure 1. Illustration of a two wheel drive system with different diameter wheels.



The challenge to making a robot like this work properly is finding the right combination of sprockets and

$$\frac{S_2}{S_1} = \frac{D_2}{D_1}$$

Equation 5

wheels that will have the same ratios. Depending on the sizes of the wheels you want to use, you may have to build a sprocket and chain based gear box between your front and rear wheels so that you can use the same motor to drive both wheels with the same linear velocity. ● ● ● ● ●

Q. I am new to robotics and I would like to get into it. What I would like to do is take a car (full size automobile) and make it radio controlled. I would most likely start with lawn mowers and go-karts. Now, I don't really know where to start, but I am guessing the *Robot Builder's Sourcebook* would be good. Could you point me in some direction?

— Joseph Whitney
via Email

A. The *Robot Builder's Sourcebook* by Gordon McComb from McGraw-Hill is probably the best single source for finding just about anything you would need to build a robot, but you are going to need to know what to do with the parts in order to build the radio controlled automobile.

This may sound silly, but the radio controlled gasoline cars you can get at the hobby store will show you how to get started. Most of the technology that makes the car radio controlled will be very similar to what you will need to do to make the automobile radio controlled. They are the best place to get started, and taking them apart and modifying them to work better is where you will learn a lot about how to remotely control an automobile.

The three most important things you need to keep in mind when doing something like this is safety, safety, and safety. A 3,000 pound car can cause a lot of damage, or even death, if a small mistake is made. A 100 pound go-kart can also cause a significant amount of damage if something goes wrong. So starting small is the right way to get rolling.

Probably the two best places to get started with this type of a project is either getting involved with your local high school FIRST (For Inspiration and Recognition of Science and Technology) team, or getting involved with building combat robots like the ones shown on TV, such as Robot Wars and BattleBots. Both of these areas involve building large radio controlled robots with a heavy emphasis on safety. And what you learn in building them can be applied to building the radio controlled automobile.

More information about FIRST can be found at **www.usfirst.org** There is a lot of information about building combat robots that can be found on the Internet and there are several books that have been published on this topic. But the best place to learn about combat robots is to actually build them and participate in a local contest. A good place to learn about the many different combat robot events is at the Robot Fighting League's website **www.botleague.com**

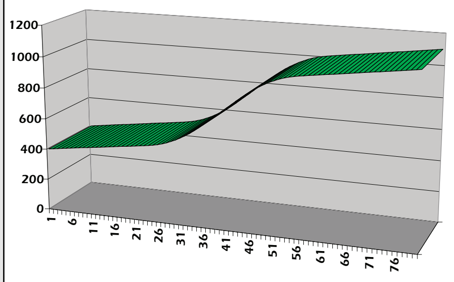
By participating in either of these activities, you will learn how to build the mechanics, the electronics, and the radio control systems to drive these robots around, and all this knowledge can then be applied to building that radio controlled automobile. ● ● ● ● ●

Q. I am using an R/C servo to create linear motion but my design prevents the use of a rack and pinion setup. So, I am using a standard servo horn with a ball joint and some threaded rod. The problem is that the travel is uneven, being faster in the middle than at the ends.

Is there a clever mechanism I can use to "linearize" this motion? Or, since I am using a BX-24 to drive the servo, is there a quick way to do this in software?

— Anonymous
via Internet

Figure 2. Servo position vs. time due to a trapezoid velocity profile.



A. The rack and pinion and the ball screw systems are two of the best ways to convert rotary motion into uniform linear motion. The linear position and velocity are uniformly proportional to the rotational position and velocity of the drive servo.

Another popular method is to use cams to move a sliding bar. Both position and velocity profiles as a function of the servo motion can be tuned for long uniform velocity motions with a short and fast return motion. Two other popular methods for converting rotary motion into linear motion are called the four bar linkage and the slider crank mechanism. The advantage to the latter two is that they are relatively easy to implement (which is probably what you are using right now), but the drawback is that the output velocity will follow a sinusoidal pattern, which also sounds like what you are getting in your setup.

There are many clever kinematic mechanisms that can approximate a "linear" motion from a rotary motion. An excellent source for different types of mechanisms is the four volume set *Ingenious Mechanisms* by Jones and Horton. But since you have a design constraint that does not allow a rack and pinion solution, you may not have the room to implement one of these clever kinematic solutions. Thus, you may have to use an electronic and/or software solution.

R/C servos make excellent servo motors when controlling position is the main goal. A servo is designed to move at its maximum speed to get to its commanded position, and they only slow down when it gets very near the commanded position. Controlling the veloc-

ity of a servo can be done if you command the servo to make a series of smaller move increments instead of one large positional movement. Since standard R/C servos require the commanded position to be updated every 15 to 20 ms, this can be used to our advantage.

For example, a common servo may have a speed rating of 60 degrees in 0.2 seconds. This is the same as a six degree movement in 20 ms. Now if you want the servo to move a total of 60 degrees, you can command the servo to move the total amount in one command, and then you will have to repeat this move command 10 times (10 x 20 ms = 0.2 seconds), for the servo to complete that move.

Another way to do this is to create a program loop in your microcontroller where you increment the commanded position from six degrees to 60 degrees in six degree increments.

With the same 20 ms pauses between each of these move commands, you will still get the same total net move result in the same amount of time. This represents the maximum velocity move for this servo. You can't tell it to go faster — but you can tell it to go slower.

Now if we changed the same loop to three degree steps, and still used the same 20 ms time delay between each commanded move, the servo will in effect move at half the speed as in the previous example. This is because the servo will reach the three degree point in about 10 ms, as the true velocity of the servo is still six degrees per 20 ms.

Thus, the servo will wait for 10 ms at the three degree position, until the next move commend is sent to the servo. If you use one degree incremental steps, then the servo will move at about 1/6th the maximum speed. By adjusting the incremental move distances, you can control the speed of the servo, as long as the desired speed is less than the maximum speed of the servo.

Now how does this fit in with your project? You can command the servo to move at a slower speed for its normal operation — say, half its normal speed. When you come up with situations where you need to increase the speed, use fewer and larger incremental movements, and when you want to go slower, use more smaller incremental movements.

The BASIC Stamp 2 is fully capable of doing this. You are going to have to do some experiments to get the right motion profile you want. You may have to make a look-up table with the various incremental move commands to simplify the programming of your microcontroller.

The program in Listing 1 shows an example of using a Lookup function to generate a trapezoidal velocity profile with a standard R/C servo. It is also shown graphically in Figure 2. Depending on how complex the velocity and motion control profile you want, you may want to use a dedicated microcontroller to control the servo. S

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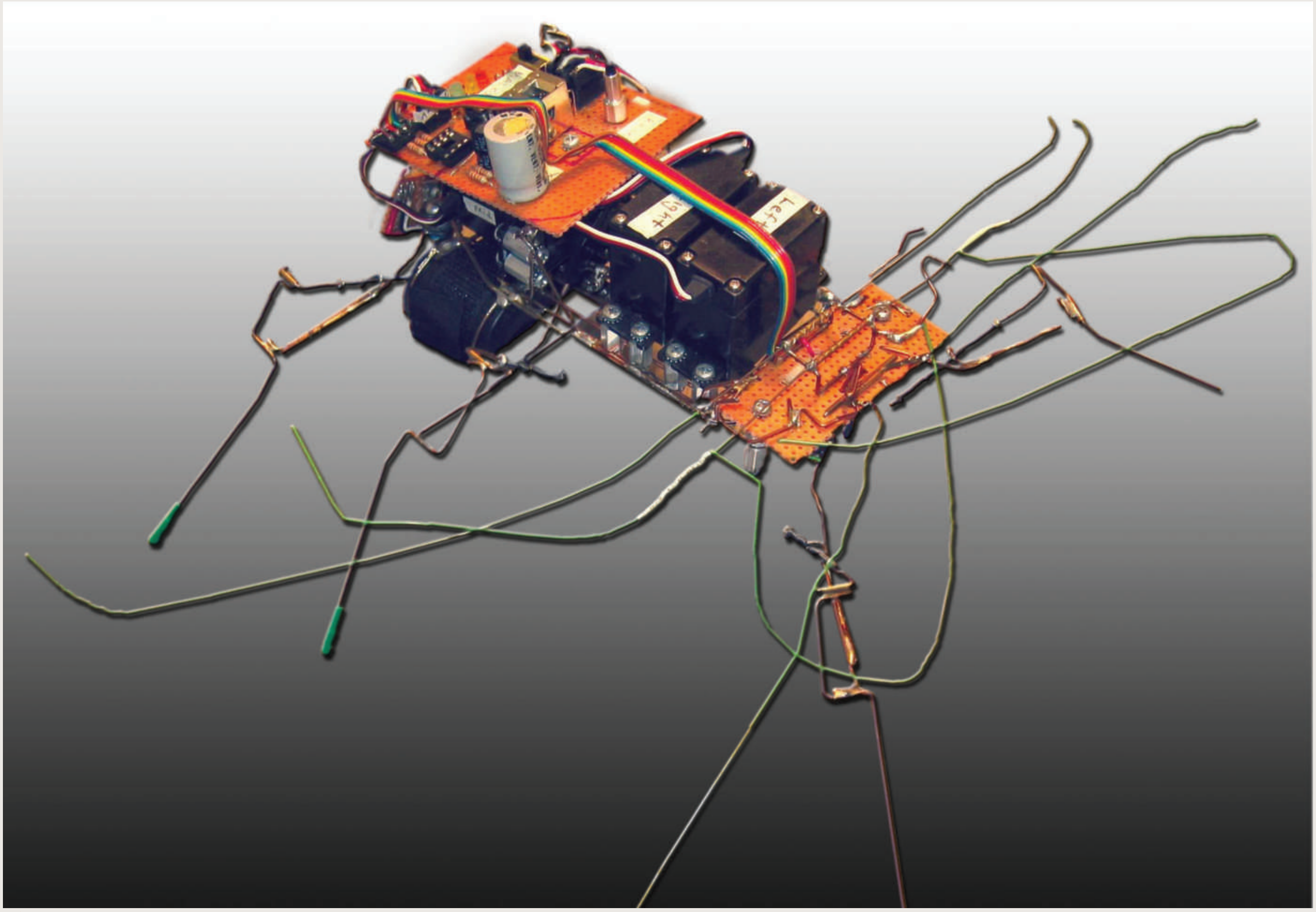
Listing 1

```
'{$STAMP BS2}
'{$PBASIC 2.5}

' Basic Stamp 2 program demonstrating
' variable speed control of a Tower Hobbies
' TS-53 standard servo, using a Lookup
' function to coordinate the velocity and
' position together.
' This servo will move through the following
' sequence:
' Move to 0 Degrees at maximum speed, ~300
' Deg/sec (60 Deg/0.2 sec)
' Move from  0 to 24 Degrees at a constant
' velocity 50 Deg/sec
' Move from 24 to 66 Degrees at a constant
' acceleration 1042 Deg/sec^2
' Move from 66 to 114 Degrees at a constant
' velocity 300 Deg/sec
' Move from 114 to 156 Degrees at a constant
' acceleration of -1042 Deg/sec^2
' Move from 156 to 180 Degrees at a constant
' velocity 50 Deg/sec

i        VAR  Word    ' Counter Variable
Value    VAR  Word    ' Position value

Main:
  FOR i = 1 TO 60    ' Move to start position
    PULSOUT 1, 400
    PAUSE 20
  NEXT

  FOR i = 0 TO 80    ' Through its paces
    LOOKUP i,
[403,407,411,415,419,423,427,431,435,438,
442,446,450,454,458,462,466,470,473,477,
481,485,489,493,498,504,512,521,533,545,
560,576,593,613,634,656,680,703,726,750,
773,796,820,843,865,886,906,923,939,954,
966,978,987,995,1001,1006,1010,1014,1018,
1022,1026,1030,1033,1037,1041,1045,1049,
1053,1057,1061,1065,1068,1072,1076,1080,
1084,1088,1092,1096,1100], Value
    PULSOUT 1, Value     ' Each period = 2us
    PAUSE 20
  NEXT
  GOTO Main     ' Restart the motion sequence
END
```

GeerHead

by David Geer
geercom@alltel.net

Testing Your Metal



Shakes Walker

"Shakes," a three-servo hexapod walker, hand sculpted and soldered together out of copper plated TIG welding rod.

The world is an ocean of parts. Junkyards and hardware stores stand among the dozens of spawning grounds for your next creation. But *finding* 'bot construction materials is not as head spinning as *knowing* what to look for.

Steels, plastics, brass and copper, bronze, aluminum, woods, and composites — these are the best. Factors like availability, cost, strength, and ease of use will influence your choice. "Availability and ease of use are the most crucial," says Roger G. Gilbertson, President of Mondo-tronics, Inc., and The Robot Store.

Proto Parts Primer

Want a 'bot to be proud of? Make your mistakes on a prototype first.

Some materials are specially suited to prototypes. Polyvinyl chloride (PVC) and plywood are cheap, easy to find, and easy to work. Plywood boxes and I-beams are very strong and have a good weight-to-strength ratio.

"PVC is relatively heavy, not as strong, and deforms, but it's useful in prototyping chassis and support structures," says Dr. Alan N. Federman, a senior NASA engineer. Aluminum extrusion is pricey, but very boss for protos.

It can be worked like a giant erector set. Cardboard, foamcore, and Styrofoam help with correct sizing and proto-making.

Heavy Metal Rave — on the Mild Side

Mild steel is common in cars and appliances. Useful in many areas of robotics, it's a favorite for low budgets. It has moderate strength, welds easily, and machines well, too. Mild steel specs into the neighborhood of a 1015. (The 15 tells you how much carbon it has, says H. Ben Brown, Jr., Project Scientist, The Robotics Institute, Carnegie-Mellon University.) As carbon content increases, so does strength, but at the expense of workability. "Take a walk on the mild side" when strength is less important than cost. Parts like fasteners come in mild steel (also in high strength steels, aluminums, and even titanium).

High Carbon

High carbon steels are in the vicinity of a 1030 or 1040 (see *AlloyInfo Reports* at All Metals & Forge Information Resources, free registration required). The more carbon, the more heat treatable and the harder it is. It can be precast or you can shape it yourself.

Music wire (piano wire) — made of hardened high carbon steel — is available in several diameters. Piano wire is good where you need a hard steel rod.

Drill rod works well where you need a shaft of a precise diameter and a certain hardness. Dowel pins are also examples of very hard steel in exact sizes, though in shorter lengths.

Chromoly Alloys (Chrome Moly)

Chromoly is a steel alloyed

FIRST Team 255

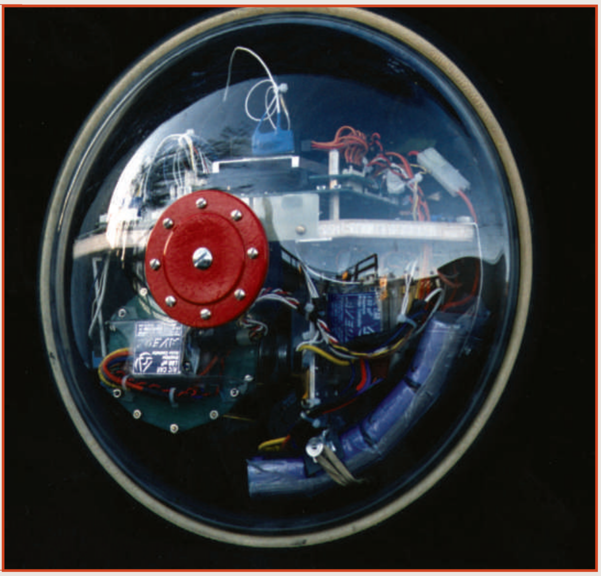
Extruded aluminum is used for final chassis construction. (2000) FIRST National Champion — Team 255, San Jose, CA.

Photo courtesy of Dr. Alan N. Federman, NASA.

The Gyrover

Gyrover is a gyroscopically stabilized, single-wheel robot built inside a 16” lightweight bicycle wheel. The domes on each side are made of polycarbonate sheet which provides transparency with good strength and impact resistance. The main platform is fabricated from a sandwich structure of two layers of 1/16” aircraft plywood with balsa wood between — this is lightweight and strong, and allows easy mounting of components. Other major mechanical parts are of 6061-T6 aluminum, which has good strength, and is low in cost and easy to fabricate.

Photo courtesy of "The Robotics Institute, Carnegie Mellon University."



(mixed) with molybdenum and chromium. Chromoly tubing can be welded into strong, light frames. As with race-cars, it's good for robots that will be doing some traveling (under their own power).

Other Steel Formats

“For robots that need to be light and strong, I like TIG rod (steel rods coated with copper used for welding). These are inexpensive, strong, and you can solder them together with a plumbing-soldering gun. It's easy to get really creative!” says Mr. Gilbertson.

Suppliers

Places to locate these and other parts and materials include McMaster-Carr, All Metals and Forge, the Human Power Source Guide, surplus outlets, and hardware stores.

The Wrap on Plastics

High Density Polyethylene (HDPE) resists impact, corrosion, and abrasion. Polycarbonate resists impact and is good for structural and gearbox housings. Acrylic can be used for optics and can be made impact resistant. Delrin is strong, chemical resistant, and has low moisture absorption. It's used for bushings and bearings. Nylon absorbs moisture.

“I use some plastics, like polystyrene, ABS, and PVC. I use lots of found parts and adapt them to new uses. For example, an ABS electrical box cover plate can become the base for a robot,” says John Kittelsrud, President, PAReX (Phoenix Area Robotics eXperimenters).

Suppliers abound on the Internet — Tap Plastics, Lowes, Menards, and GE Plastics are good places to start looking. Sheet plastic can be had from plastics dealers and hobby shops.

Brass, Copper, and Bronze

Brass machines and solders well. Its moderate strength is comparable to mild steel, though it is denser and not as stiff. "There is a property called Young's Modulous (the modulous of elasticity) that tells you the stiffness of the material as differentiated from its strength. This tells you how much it will deflect under a certain load," says Mr. Brown. For parts where strength is not as important as machining and soldering, brass is worth considering, as well.

Copper is good for electrical and thermal conductivity. It's used for wiring and can be easily soldered. Phosphor bronzes are used in springs where toughness and elasticity are required.

Aluminum Alloys

Aluminum alloys can be heat-treated to varying hardness. 6061 T-6 is a very good general-purpose alloy. It machines pretty well and can be welded. It's available in many shapes like bar stock, beams, channels, and flat sheets. “That's what we use most generally,” says Mr. Brown.

7075 T-6 is stronger than 6061 due to the additional alloying components: copper, zinc, and titanium. The Robotics Institute uses that to meet high strength requirements. It's more expensive and not available in as many form factors.

Alloy 2024 T-4 has a strength 75% greater than 6061. "There's a number called yield strength that's important. That's the stress level at which the material permanently deforms. You usually want to stay well below that," says Mr. Brown. Alloy 2024 has a 47 kPSI (thousands of pounds per square inch) yield strength. The 6061 T-6 is 40 kPSI and the 7075 is 73 kPSI. All aluminums will have about the same weight or stiffness, but differing strengths.

Steel is about three times as dense as aluminum and about three times as stiff. Though the two metals seem equal in this respect, aluminum is often the better choice. Given two large structures of the same weight, an aluminum one can be stiffer than steel.

Carbon Fiber

Among Kevlar, carbon fiber, and fiberglass, carbon has the highest stiffness-to-weight ratio, and a fairly high strength-to-weight ratio. With com-

posite materials, you can direct the fibers according to where you want the strength. For example, if you want a beam to resist bending, you'll want the fibers aligned lengthwise.

Fiberglass is of lower cost, lower strength, and not surprisingly, more frequently used. Kevlar, on the other hand, is as strong but not as stiff as carbon. You can buy composite materials in rods, square bar, or sheet stock. You can also buy raw fibers or cloth and add the resin yourself to cure it into a structure of your choice.

Wood

"Wood is low in cost and density, light in weight, and easy to cut and drill. It's something we use a lot for larger structures," says Mr. Brown. Spruce — once used in small aircraft — is good for structures. Pine is also a good structural material. Plywood — layers of wood laminated so the grains are at different angles for strength — is good for stable construction that won't warp.

"Plywood (1/2-inch thick birch) is a great prototyping material," says Dr. Federman. Light and easy to machine, it can be formed into I-beams or boxes with glue, hand tools, and drywall screws. "Plywood is a sophisticated, laminated wood product that can also be used to add strength to sheet metal components," says Dr. Federman.

According to Mr. Kittelsrud, hobby packs of pre-cut 1/4-inch x 1/4-inch hardwoods (available at hobby stores) are great to work with (think "wooden LEGOS"). "I use them because I don't have a big shop to rip lumber down to smaller pieces," says Mr. Kittelsrud. These are handy for body frames and mounts for electronics.

Extra Stuff, Notes, and Pointers

Additional Materials Sources

Check the computer junkyard for modular steel and aluminum shelving units with pre-drilled L and square beams. A hacksaw will do for cutting them to size. The Home Depot also carries myriad construction materials on the cheap — electrical conduit tubes, aluminum fence posts, and steel hardware.

Don't Dive in Empty-handed

"You don't have to have a full-on Computer Numerically Controlled (CNC) mill set up at home or a degree in mechanical engineering to build a robot," says Mr. Kittelsrud. Small power tools and hand tools will bring most materials into submission.

A drill press and power sander are recommended for large or heavy woods and plastics. "If you use steel or heavy aluminum, you will need some serious metal working equipment — a mill, lathe, welder, cutters, and bits," says Mr. Gilbertson.

Do Most Home Roboticists Prefer Raw Materials to Kits?

"This is a darn good question. In all of the contests I have been to, the scratch-builts have always outnumbered the kits. I think it's part of the whole DIY robot thing," says Mr. Kittelsrud. Precast parts that just go together are often too easy, like painting by numbers. S

Resources

Killer Bee

Killer Bee, 500-gram mini sumo robot.

Photo courtesy of John Kittelsrud.

Millibot Train

The Millibot Train combines multiple, tracked modules into a single train, with articulated joints for enhanced mobility. This working model uses the Fusion Deposition Modeling™ (FDM) rapid prototyping method for fabrication of its major parts. FDM allows fast, low-cost fabrication of plastic parts, moderate dimensional resolution (~.010"), and production of parts — such as the hollow-core sprockets for the tracks — that could not be made by conventional machining. Other parts include standard hobby servos to drive the tracks, music wire axles, and tubular brass, plus small toothed belts to make the tracks.

Photo *courtesy of The Advanced Mechatronics Lab, Carnegie Mellon University.*

Orb of Doom

"The Orb of Doom" is a radio-controlled "hamster ball" robot with a shell of carbon-Kevlar over a foam core form. It met its own, personal doom at the Second Robot Wars event in 1995.

Photo courtesy of Roger G Gilbertson, **RobotStore.com**

Resources

The Robot Store
www.robotstore.com

Alloy Info Reports, All Metals & Forge Information Resources
www.steelforge.com/infoservices/infoservices.asp

McMaster-Carr
www.mcmaster.com

The Human Power Source Guide
www.ihpva.org/SourceGuide

Tap Plastics
www.tapplastics.com

Lowes
www.lowes.com

Menards
www.menards.com/nindex.html

GE Plastics
www.geplastics.com

The Home Depot
www.homedepot.com

MENAGERIE

Send us a high-res picture of your robot with a few descriptive sentences and we'll make you famous. Well, mostly. menagerie@servomagazine.com

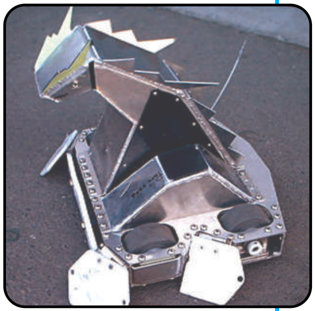
75 MHz INCU Bus

R. Kieronski, Newport, RI

Gliding slowly along the floor, its lighted eyes cast a pattern on the wall in the direction of its video camera gaze. Maneuvered by the operator through a radio link. If you are chosen, it will squirt you with its finger.

It is as a metaphor for the information systems that silently exercise their surveillance powers on us ... at least you can see this one.

www.lumion.net



Green Eye Silver Dragon

Suni Murata, Somewhere in CA

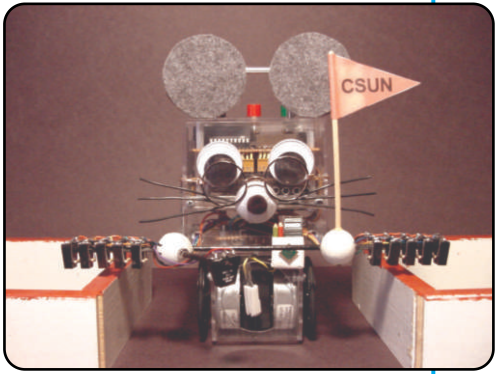
Thirty pound fighting robot made of sheet aluminum and fast electric motors. Will sport a pneumatic flipping tail in the future. My basic philosophy: Learn from everyone else and incorporate the design that works. **tmurata20@aol.com**

Dexter

Steve Benkovick, Northridge, CA

Built to compete in the 10 foot square IEEE MicroMouse maze, Dexter has a 68HC11 brain and 32K of RAM. It is propelled by unipolar steppers, powered by 10 NiMH batteries and uses five IR sensors on each side to detect walls within the maze.

www.micromouseinfo.com



This electric guitar playing robot from the band **Captured! By Robots!** is over seven feet tall, weighs 130 pounds, and reportedly *rocks harder than you.*

www.capturedbyrobots.com

GTRBOT666

JBOT, San Francisco, CA

New Products

ACCESSORIES

Multi-Position Chargers

Cell-Con Incorporated announces the availability of its custom, multi-position chargers. Multi-position chargers are available for simultaneous charging of multiple battery packs assembled from one of the following chemistries: lithium ion, NiMH, NiCd, or sealed lead acid.

These chargers are based on existing designs and technology that is easily adaptable to specific customer requirements. Fast project turn around time (30-180 days) and a minimal financial investment are typical. Small and large volumes accepted.

Customer specified options such as charging method (constant current/constant voltage, smart, constant current, overnight, and float), open frame, and battery refresh capabilities are available.

Prices range from a few hundred dollars to a few thousand dollars depending upon the complexity of the charger and its volume.

Cell-Con Incorporated is a US-based manufacturer of custom power systems consisting of single position chargers, multiposition chargers, custom battery assemblies, power supplies, and analyzers.

For further information, please contact:

Cell-Con Incorporated
305 Commerce Dr., #300
Exton, PA 19341
Tel: **610 • 280 • 7630**
Fax: **610 • 280 • 7685**
Email: **sales@cell-con.com**
Website: **www.cell-con.com**

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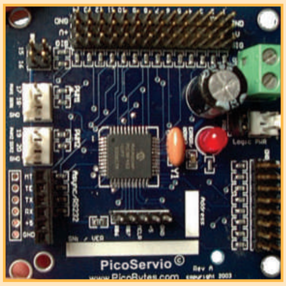
CONTROLLERS & PROCESSORS

Servio™ — The New R/C Servo and I/O Slave Controller



PicoBytes, Inc., a leading innovator of robotics and automation controllers, has released its new serial R/C servo and I/O slave controller — Servio™ . It is an intelligent serial R/C servo and I/O slave controller capable of controlling up to 20 R/C servos with 16-bit resolution and 256-speed settings. It also has eight A/D converter ports capable of 10-bit resolution at 40 samples/second, with two PWM signal generators capable of up to 10-bit resolution with direction control for H-Bridge connections and two-

channel R/C decoder with differential steering override. Unused A/D and servo ports can be configured as digital I/O.

Powerful features such as monitoring, servo sweep, and sequence functions offload the burden of constant polling and control from the master CPU. Unlike other products, there are no complicated languages to learn. All this power is available by sending simple serial command at rates of up to 115,200 bps, which can be accomplished with any computer or MCU.

A comprehensive user and technical manual explains all aspects of operation with many code examples.

Servio consumes less than 14 mA and weighs only 0.8 ounces (22 grams) in a 2.5" x 2.5" (63mm x 63mm) footprint, which makes it ideal for battery and mobile operations.

For further information, please contact:

PicoBytes, Incorporated

10674 Chinon Cir.
San Diego, CA 92126
Tel: **858 • 549 • 7394** Fax: **858 • 581 • 3375**
Email: **sales@picobytes.com**
Website: **www.picobytes.com**

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MOTORS

SM3416 SmartMotor™ — A NEMA 34 Size Low-Cost Integrated Servo Motor

Animatics has launched the SM3416, NEMA 34 size low cost integrated servo motor. The SM3416 is exceptional, producing more than 1 NM of torque at an unprecedented low cost.

Those who love the benefits of integrated servo motors have been clamoring for a low cost product in the NEMA 34 size and torque range. While it sets a new precedent in low cost integrated motion control, the SM3416 has all the features you've come to expect from SmartMotors — a true departure from the wiry mess of the traditional component solutions.

In 1994, when Animatics released the world's first line of fully integrated servos, with all of the positioning electronics, driver circuits, and the encoder built into a single small unit, the industry was slow to accept the radical departure from conventional motion control. Today, that fear is gone, the technology is proven, and the integrated servo market is touted by independent studies as the fastest growing market within the motion control industry.

The SM3416 is a SmartMotor in a familiar package. Based on Animatics' patented, award winning design, the SM3416 is the final chapter of the highly successful line of OEM series SmartMotors. Comprised of both NEMA 23 and NEMA 34 size SmartMotors, the OEM Series delivers competitively priced integrated motion control to the high volume OEM and integrated markets.

Animatics Corporation is the world leader in integrated motion control. Animatics is located in the heart of Silicon Valley and designs, manufactures, and markets motion control products for industries ranging from semiconductor, nuclear, automotive, and machine tool to traditional industries such as CNC. Animatics' strength lies in using technological innovation to meet complete solutions for motion control. For further information, please contact:

Animatics Corporation

3050 Tasman Dr.
Santa Clara, CA 95054
Tel: **408 • 748 • 8721**
Email: **response@animatics.com**
Website: **www.animatics.com**

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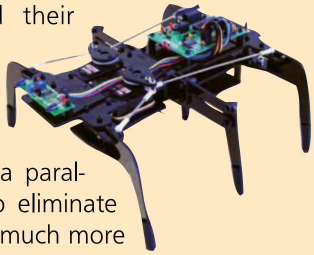
ROBOT KITS

Hexapod Walker Kit



Lynxmotion has introduced their totally redesigned Hexapod 1 Walker kit. This walker uses the traditional three servo design with a twist. Lynxmotion has implemented a parallelogram on the lifting legs to eliminate friction. This makes the walker much more efficient than other designs. The walker is made from precision laser-cut Lexan (polycarbonate) material. The assembly is easy using common hand tools. The all "nuts and bolts" construction means there is no glue or tape. All of the legs are actuated by quality ball links for reliable operation. The kit uses powerful Hitec HS-422 servos. There are optional "punch-outs" to add either a standard or a micro-size servo to the front. This makes adding a pan and tilt camera mount or panning ultrasonic sensor very easy. The chassis will accept either our Next Step carrier or an OOPic-R microcontroller. The Next Step can use the BS-2, the BASIC Atom, or the OOPic-C microcontroller. The microcontroller can be mounted on top the robot, or inside to provide room for additional peripherals.

The robot is available as a bare chassis (including servos) for those who want to roll their own electronics. It is also available in several combo kits which include everything needed to get the robot up and running right away. With the addition of the optional "Pan & Tilt" camera mount, a Hitec remote control set, and a camera and video transmitter, the robot can be configured as a remote piloted rover. Prices start at $99.95 for a truly affordable robot experimentation platform. Stop by the Lynxmotion website to see the assembly guide, video of the robot in action, and much more. For further information, please contact:

Lynxmotion Incorporated

PO Box 818
Pekin, IL 61555
Tel: **866 • 512 • 1024**
Fax: **309 • 382 • 1254**
Email: **sales@lynxmotion.com**
Website: **www.lynxmotion.com**

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WEASEL — A Touching and Seeing Robot Kit

OWI introduces the Weasel — a tenacious little robot warrior that embodies two sensors that allow it to "see" a line or "feel" its way along walls and around corners. The two motors and contact sensor activate the wall sensing micro switch to control the motor's on/off operation that determines the path of a wall. It is the classic robot design using the "Left Hand Rule" to escape mazes.

With OWI's continued pursuit in making robots "smart," they have added an additional feature to this little bundle of energy ... a sonic tracking system. Beneath Weasel's sturdy plastic base, you will discover phototransistors that enable it to detect and follow a black line. The Weasel also boasts a three-speed gearbox which will help navigate at the velocity you determine. Quick and easy to assemble, this is a beginner robot that makes great entries for robotic competitions, robotic workshops, afterschool programs, special events, gifts, science enrichment camps, and classroom activities. It has a suggested selling price of $24.95. For further information, please contact:

OWI Incorporated

17141 Kingsview Ave.
Carson, CA 90746
Tel: **310 • 515 • 1900** Fax: **310 • 515 • 1606**
Email: **owikitsales@pacbell.net**
Website: **www.robotikitsdirect.com**

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Mind Candy For Today's Roboticist

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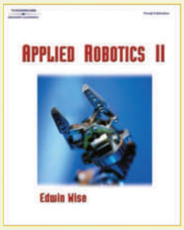
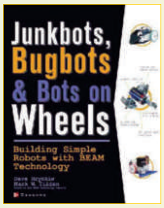
Applied Robotics II
by Edwin Wise



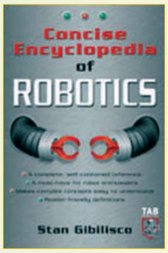
Instructive illustrations, schematics, part numbers and sources are also provided, making this book a "must" for advanced builders with a keen interest in moving from simple reflexes to autonomous, AI-based robots. Create larger and more useful mobile robots! Ideal for serious hobbyists, *Applied Robotics II* begins by discussing PMDC motor operation and criteria for selecting drive, arm, hand and neck motors. **$41.95**

JunkBots, Bugbots, and Bots on Wheels: Building Simple Robots With BEAM Technology
by David Hrynkiw / Mark Tilden



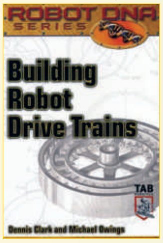
Ever wonder what to do with those discarded items in your junk drawer? Now you can use electronic parts from old Walkmans, spare remote controls, even paper clips to build your very own autonomous robots and gizmos. Get step-by-step instructions from the Junkbot masters for creating simple and fun self-guiding robots safely and easily using common and not-so-common objects from around the house. Using BEAM technology, ordinary tools, salvaged electronic bits, and the occasional dead toy, construct a solar-powered obstacle-avoiding device, a mini-sumo-wrestling robot, a motorized walking robot bug, and more. Grab your screwdriver and join the robot-building revolution! **$24.99**

Concise Encyclopedia of Robotics
by Stan Gibilisco



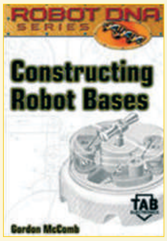
This handy collection of straightforward, to-the-point definitions is exactly what robotics and artificial intelligence hobbyists need to get and stay up to speed with all new terms that have recently emerged in robotics and artificial intelligence. Written by an award-winning electronics author, the *Concise Encyclopedia of Robotics* delivers 400 up-to-date, easy-to-read definitions that make even complex concepts understandable. Over 150 illustrations make the information accessible at a glance and extensive cross-referencing and a comprehensive bibliography facilitate further research. **$19.95**

Building Robot Drive Trains
by Dennis Clark / Michael Owings



This essential title in McGraw-Hill's *Robot DNA Series* is just what robotics hobbyists need to build an effective drive train using inexpensive, off-the-shelf parts. Leaving heavy-duty "tech speak" behind, the authors focus on the actual concepts and applications necessary to build — and understand — these critical force-conveying systems. If you're hooked on amateur robotics and want a clear, straightforward guide to the nuts-and-bolts of drive trains, this is the way to go. **$24.95**

Constructing Robot Bases
by Gordon McComb



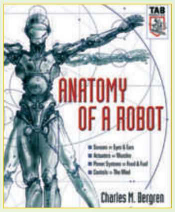
Here is the first title in the innovative new *Robot DNA Series* from McGraw-Hill, the premiere publisher of references for the robotics hobbyist. Author Gordon McComb focuses on the basic concepts and specific applications you need to build efficient robot bases – and have a great time in the process. In the clear, easy-to-follow style that has made him a favorite among robotics fans, Gordon tells you how to get things up and running using only inexpensive, easily-obtained parts and simple testing equipment. Detailed enough to get the job done, but written with the amateur hobbyist in mind, *Constructing Robot Bases* is your first point of reference when designing and building this essential subsystem. **$24.95**

Programming Robot Controllers
by Myke Predko

In this innovative addition to the *Robot DNA Series*, author Myke Predko demonstrates how robot controllers are programmed using the versatile Microchip PICmicro Microcontroller. The focus of the book is on the least understood aspect of robot design: integrating multiple sensors and peripherals software that will work cooperatively and allow for a simple high-level control application. To explain the concepts presented in the book, Myke uses off-the-shelf parts and a "C" programming language compiler that is included on the CD-ROM. **$24.95**

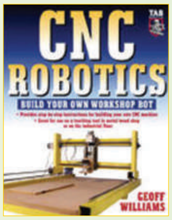
We accept VISA, MC, AMEX, DISCOVER
Prices do not include shipping and may be subject to change.

Anatomy of a Robot
by Charles Bergren



This work looks under the hood of all robotic projects, stimulating teachers, students, and hobbyists to learn more about the gamut of areas associated with control systems and robotics. It offers a unique presentation in providing both theory and philosophy in a technical yet entertaining way. **$29.95**

CNC Robotics
by Geoff Williams



Now for the first time you can get complete directions for building a CNC workshop bot for a total cost of around $1,500.00! *CNC Robotics* gives you step-by-step, illustrated directions for designing, constructing, and testing a fully functional CNC robot that saves you 80 percent of the price of an off-the-shelf bot — and that can be customized to suit your purposes exactly, because you designed it. **$34.95**

PIC Robotics: A Beginner's Guide to Robotics Projects Using the PIC Micro
by John Iovine

Here's everything the robotics hobbyist needs to harness the power of the PICMicro MCU! In this heavily-illustrated resource, author John Iovine provides plans and complete parts lists for 11 easy-to-build robots each with a PICMicro brain. The expertly written coverage of the PIC Basic Computer makes programming a snap — and lots of fun. **$19.95**

Robot Mechanisms and Mechanical Devices Illustrated
by Paul Sandin

Both hobbyists and professionals will treasure this unique and distinctive sourcebook — the most thorough and thoroughly explained — compendium of robot mechanisms and devices ever assembled. Written and illustrated specifically for people fascinated with mobile robots, *Robot Mechanisms and Mechanical Devices Illustrated* offers a one-stop source for everything needed for the mechanical design of state-of-the-art mobile 'bots. **$39.95**

BUILD A LOW COST SOUND SENSOR

This Month's Projects

Sensing a sound with a robot or microcontroller can be challenging. If one or more of the sounds in question is relatively brief, the microcontroller must suspend other activities and spend it's time waiting for the sound to occur.

This can lock up the microcontroller in a non-productive polling activity or else risk missing the pulse by doing something else and then getting back to the sound input.

I present a circuit that offloads some of the processing work to an analog detector with persistent memory.

A common task involving sound is to look for an average sound level in a particular environment. If only instantaneous values are available to the computer, some form of data storage and averaging must be carried out.

Using a sound sensor with the capabilities to stretch pulses and to sense average sound levels can relieve these tasks.

by Paul Badger

Art by Bryce Kho

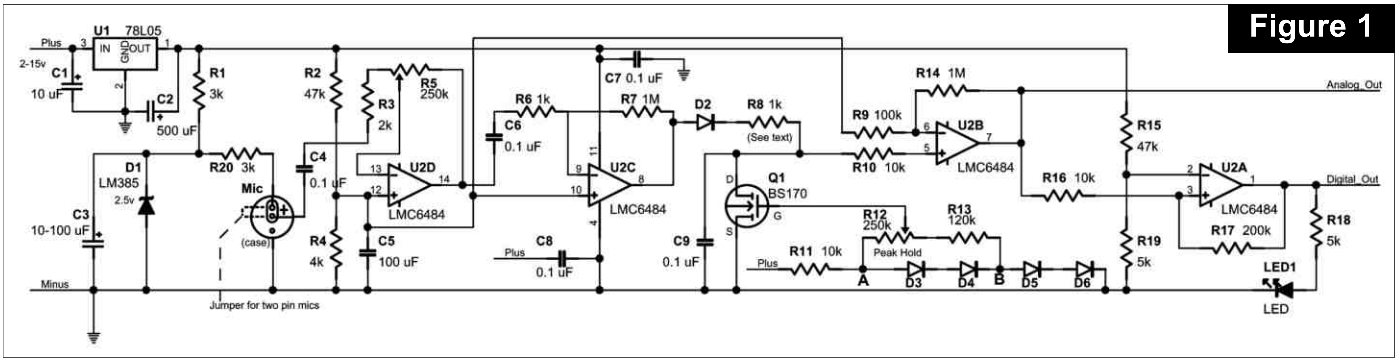


Figure 1

This small sound sensor — which runs on 3-15 volts and features both analog and digital outputs — was designed for my classes in physical computing at an art school. It introduces students to the usefulness of op-amps and illustrates several op-amp configurations. My students have found many uses for the sensor including directly driving high efficiency LEGO motors, controlling sound activated sculptures, sound-modulated lighting projects, as well as sound inputs for microcontrollers and robots.

How it Works

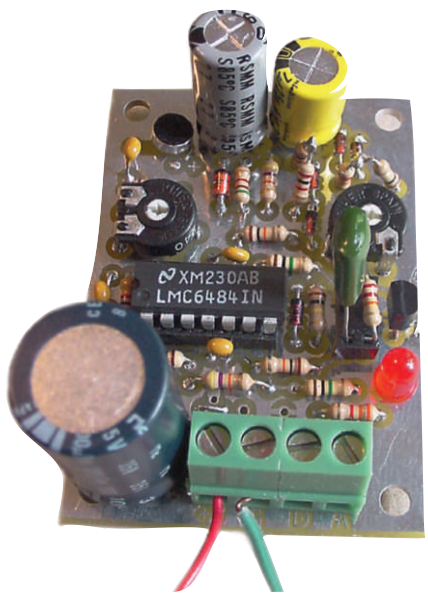
The sensor uses a cheap electret microphone element to sense and amplify sounds. This signal is then rectified by a peak detector which converts the sound signal into a ground referenced DC voltage, holds this signal, and then lets it sink back to ground level as slowly as desired.

A quad op-amp does all the signal processing. The first two op-amps are used to amplify and find the peak of the audio signal. The third op-amp buffers the voltage across the holding capacitor and supplies an analog output signal. The final op-amp is used as a comparator to produce a digital on/off output signal from the smoothly varying analog signal.

Many of the sound sensor circuits I have seen using a single op-amp to amplify microphone signals are less than optimal because the open-loop gain of most op-amps is just barely adequate to amplify an audio signal from standard electret microphone elements to a useful level. I have chosen to provide three stages to insure that there is enough gain (audio sensitivity) for even the softest signals. Now whether your microcontroller can be programmed well enough to pull the softest signals out of the noise is another story.

The Gory Details

Referring to the left side of Figure 1, U1 is an optional 78L05 regulator. When a signal is being amplified by a factor of 100,000 it only takes a small noise component in a power supply line to seriously degrade the desired signal. DC moto s are often the prime offenders in this regard with their brushes, inductive loads, and heavy current draw, which



often seem to radiate low level grunge back along the power lines. One of the best ways to deal with this noise is to provide a separate battery or power supply. (Don't forget to tie the grounds together at a "star" point.) This is not always practical so a local regulator with bypass capacitors is another cheap and effective cure.

If you don't use the regulator, just jumper the input pad to the output pad on the board and omit C1. There is also an advantage in not using the regulator, in that you can easily re-purpose the sensor for a higher voltage output if a lower voltage regulator is on the board. The microphone element can be any inexpensive electret microphone element. I had originally used a higher gain three lead mic that I found at Hosfelt Electronics. Just jumper the positive and signal pads for the more common two lead types. R1 and the zener voltage reference IC lock the microphone bias to 2.5 volts. This IC can easily be replaced by a 3 to 9 volt zener if you have one on hand. Besides providing a noise-free supply to the mic, the zener's other job is to keep the mic voltage below 10 volts, in case a higher supply voltage is being used.

The voltage at the non-inverting input of A1 (pin 12), is set by R2 and R4 at slightly above the negative rail and also serves as the reference voltage for amplifiers A2 and A3. The capacitors across the microphone bias voltage divider (C8) and the reference voltage divider (C9) are bypass capacitors that form low pass filters. Again, the goal is to prevent variations in the power supply from appearing as a signal. The electret microphone's signal is coupled through capacitor C1 into the inverting input of op-amp A1, that is set up as an inverting amplifier, the gain of which is set by the input and feedback resistors by the formula: Gain = Rf / Rin. A slight complication here is that the input resistor is made up of R3 plus any resistance that is to the "left" (in the sense of the schematic not the actual part) of the potentiometer wiper. The feedback resistance is made up of any resistance to the "right" of the pot wiper. This ratio sets the maximum gain at 250K/2K = 125 and the minimum gain at the lower limit of the pot, essentially zero, allowing the pot to have a larger control

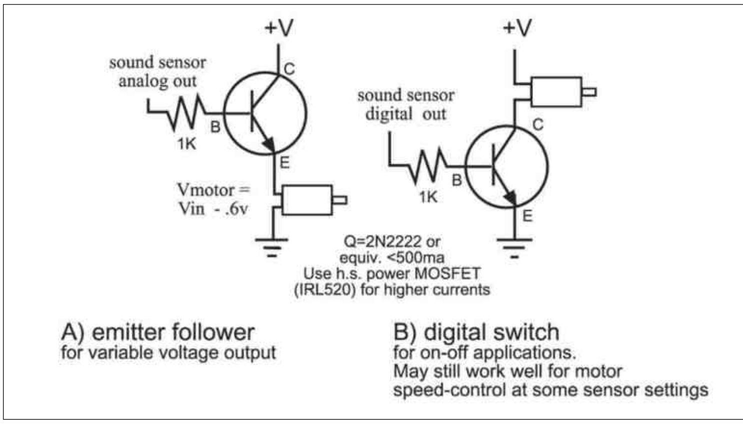


Figure 2

range than if it had just been used as the feedback resistor. By the way, only an inverting op-amp configuration can be used to reduce a signal in this way because the non-inverting configuration's minimum gain is one (unity).

C6, similar to C4, acts to pass the AC signal while blocking any DC bias. Both C6 and C4 also act as mild high-pass filters, so if you wanted the sensor to favor higher frequencies, you could experiment with smaller capacitor values. The math for the corner (-3dB) frequency is supposed to be F = 159,000/R6 * C6 (with C6 in microfarads). A2 is also set up as an inverting amplifier with a gain equal to Rf/Rin = R7/R6 = 1,000. Diode D2, R8 and C9, and the Q1 network form a peak detector circuit. Diode D2 charges C9 through resistor R8 and prevents it from discharging when the voltage falls beneath the peak. With the MOSFET biased off, the capacitor discharge times can be as long as 45 seconds. For longer times, use a larger capacitor, at the expense of a slightly less accurate response, as the op-amp has a finite ability to quickly charge larger capacitors.

R9 also limits the response of the peak detector and can be increased to yield a smoother charge curve. This allows the peak detector to function more as an average sound level detector because brief pulses will tend to be gone before the peak-hold capacitor can fully charge but more sustained sounds will eventually charge the capacitor. When I built the circuit, I cut off two positions of an IC socket to mount R8 and C9, which allowed me to easily experiment with different timing constants. R9 should be 200 ohms minimum. The MOSFET Q1, along with R10-R12 and D3-D6, comprise a network that bleeds the charge on C9, controlling the speed with which the voltage on C9 returns to ground after experiencing a transien t such as a loud noise. The remaining components in the network bias the outside legs of pot R11 at about 2.4 vold and 1.6 volts, which comprise the full-on (for our purposes) and full-off points of Q1. The wiper goes to the gate of Q1 controlling the resistance of the MOSFET. Amplifier A3 is configured as a non-inverting amplifier whose gain is set by resistors R9 and R14 by the slightly different equation: Gain = 1 + Rf/Rin = 1 + R14/R9 = 11. This gain helps boost even the weakest sounds to a full scale output. The non-inverting configuration of A3 with its very high input impedance also isolates the holding capacitor from high current loads.

Amplifier A4 is configured as a comparator with its output swinging from full high to full low when the pin 3 voltage surpasses the reference voltage at the inverting input (pin 2), which is set by the ratio of R14 to R19. Specifically Vref = Vsupply * R19/(R14 + R19) and is an arbitrary (and non-critica) value that I chose to be slightly above the "noise floor" while viewing it on an oscilloscope. Finally, the input and feedback resistors R16 and R17 serve to give the comparator some positive feedback to create hysteresis, which is a "snap" action that helps clean up noisy, borderline signals. The ratio of R16 to R17 sets the hysteresis to 1/20. This creates a zone

Parts List

Resistors	**Unless noted, all 1/4 W, 10%**
R1, R20	3 K
R2, R15	47K
R3	2 K
R10, R16, R11	10 K
R4	4 K
R6	1 K
R7, R14	1 M
R8	1K, (see text), 200 Ω minimum
R9	100 K
R13	120 K
R17	200 K
R18, R19	5 K
R5, R12	250 K trimpot
Capacitors	
C1	10 to 100 µF 25v tantalum or electrolytic (see text)
C2	500 µF 25v electrolytic
C3	10-100 µF 16v electrolytic
C4, C6 - C8	0.1 µF 25v ceramic or monolithic
C5	100 µF 25v mylar, polypropylene or monolithic
Semiconductors	
D1	LM385LP-2-5 2.5 vref (TO-92)
D2	1N914 or 1N3595 low leakage diode
D3 - D6	1N914 (or equivalent)
Q1	BS170 N-channel MOSFET
U1	78L05 regulator (see text)
U2	LMC6484 quad R/R op-amp or LM324 (see text)
LED	Any LED
Miscellaneous	
Mic	2 or 3 lead electret microphone (Hosfelt MIKE-ET)
Velleman DC Controlled Dimmer Kit (Jameco 128901)	

A double-sided plated-through PCB for the sound sensor is available for $10.00. It is not solder-masked or silk-screened. Please include either a SASE (preferred) or $1.00 for shipping. Contact Paul Badger, First Strike Graphics, 349 Morris Avenue, Providence, RI 02906.

where the input signal can vary without switching the output.

Odds and Ends

I have specified two different op-amps and each have pros and cons. The LMC6484 op amp is a "rail-to-rail input/output" CMOS device whose inputs and outputs both include the supply rails, which is especially important with sensors running in the 2 to 5 volt range. The LM324 alternative is dirt cheap and ubiquitous, but can only swing its output to within 1.5 volts of the positive supply rail. The LM324 also has about 20 milliamps more output drive, which is useful if you plan to drive a small relay or motor directly from the sensor.

Circuit Construction

The resistors and capacitors are all non-critical, so don't hesitate to use slightly different values if you want to build from parts on hand. This is a high gain circuit so a printed circuit board with a large ground plane is recommended. It is certainly possible to build the circuit on a perf board with neat construction with the shortest practical leads being a good idea. There are numerous uses for the sensor, both on robots as well as in general general tinkering.The analog output of the sensor can be directly interfaced to a Velleman DC controlled light dimmer kit to provide a cheap and easy sound-activated lighting system. When using a 5 volt input, the best results are obtained by reducing the size of the optocoupler input resistor.

The sensor can easily function as a sound-operated motor control, either by using the analog output with an emitter follower transistor or by using the digital output with a switching transistor (Figure 2). With a microcontroller or BASIC Stamp, the sensor can provide input via an ADC, or directly from the digital output to a microcontroller pin. Another idea that I have used in conjunction with microcontrollers is to use a sensor as a kind of sonic memory, so that the micro can hang out in a low power sleep cycle and once every 10 seconds or so wake up and check to see if anything is happening. If a high level sound has been sensed then the micro wakes up and does something.

When done, it resets the sensor by asserting a pin high that is wired to the bleeder MOSFET's gate and then sets this pin back to the high impedance "input" state. Another idea for using the sensor is in the area of frequency sensing — this will be covered in a future article along with some BASIC Stamp code examples.

An editable schematic is available on the Servo website, **www.servomagazine.com**. I'll post any relevant revisions or reader feedback on my website at **www.paulbadger.org** and you can reach me at **paulbadger@earthlink.net**

BATTERY FUEL GAUGE

by Fernando Garcia *IC software by Francisco Peña*

FEW THINGS in electronics seem so simple in appearance, yet in actual implementation such a difficult task, as the means to determine the total available energy in a rechargeable battery.

Measure the battery voltage? Well, not quite. For starters, the measurement requires to be open-circuit voltage — something that it is not feasible in most applications. Then there is the fact that different battery chemistries have very different discharge characteristics. For instance, nicads have a fairly flat voltage vs. charge characteristic, whereas lead-acid suffer a substantial drop in voltage. Then there is the temperature coefficient of the battery voltage itself. The list goes on and on.

An accurate battery fuel gauge, as these circuits are called in reference to the familiar automotive gas gauges, are in reality quite challenging circuits. These are usually customized for the application. As shown in Photo 1, a commercial version of the circuit is fairly complex, and thus, it is no wonder that "smart" battery packs can cost $50.00 or more. This particular device came from a camcorder, but cell phones, PDAs, and laptop computers have similarly complex devices.

On the other end of the spectrum, there are companies which make specialized fuel gauge monitors. Texas Instruments offers a large portfolio of devices, which are very powerful and have many features. But to operate them properly, substantial engineering and programming effort is required.

One has to determine and program battery coefficients like self discharge characteristics, temperature coefficients, charge/discharge efficiency ratios, and other such things. This is way too much effort for a simple project. Still, if you are curious, visit the Battery Management link at their website, **www.power.ti.com**

I, however, was interested in a circuit which would provide an improvement over the simple open circuit voltage reading, without the complexity and sophistication of the TI devices.

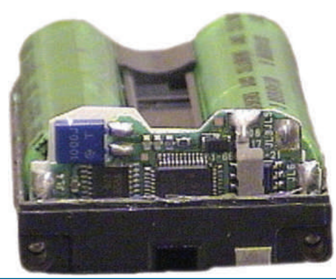


Photo 1
Battery Pack

In a battery, this means measuring its charge, or amp-hours. Therefore, one would only require a current sampling resistor, an amplifier to convert that miniscule resistor voltage to a useful level, then to a voltage to frequency converter, and finally to a bunch of cascaded counters and a display driver.

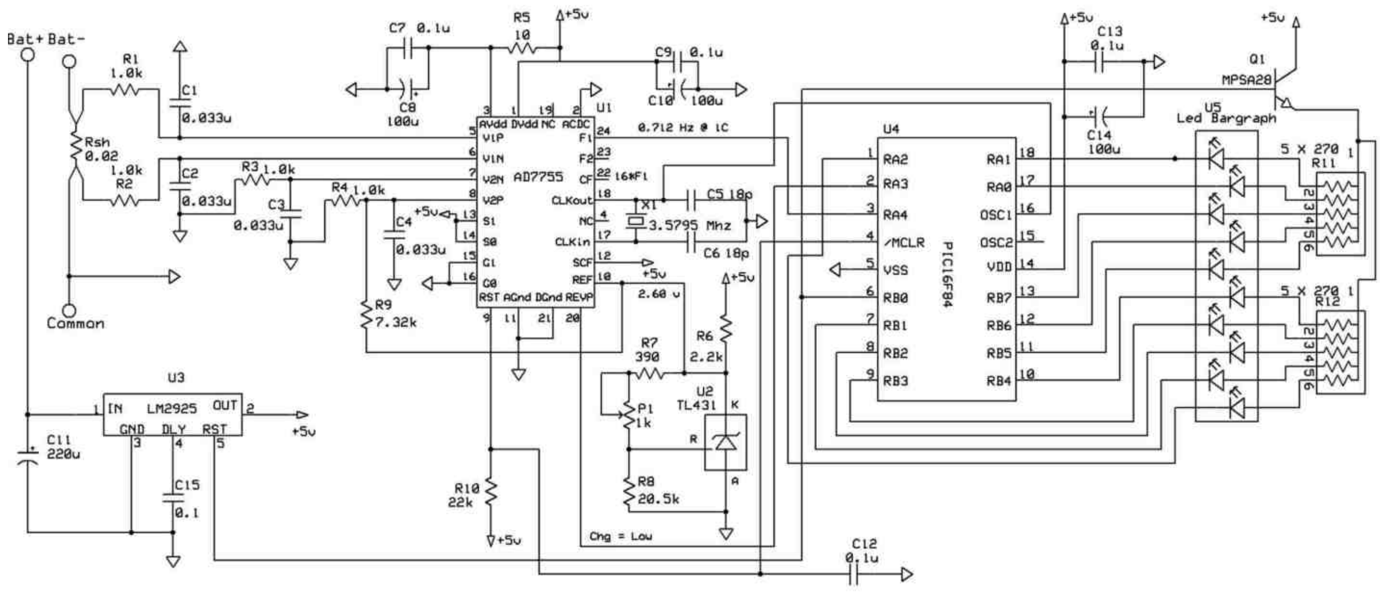
The result was a straightforward circuit that was not very sophisticated, but would work. One flaw was that it would only measure battery discharge, such that the battery had to be fully discharged and then recharged for the reading to be accurate. What if I wished to partially charge the battery, and then continue with the discharge? You know, like one always does with a vehicle, partially filling your fuel tank.

After some thinking, I came up with even more circuit requirements: an absolute value circuit previous to the V/F converter, a comparator to detect the current polarity, a negative supply to allow the operational amplifiers to swing to a negative voltage, counters with up/down capabilities, overcoming their short count sequences, etc. Suddenly the circuit was not simple anymore!

I built a prototype, but it just was not elegant. It did work, but it was way too intricate. There must be a better way! I knew I could use a microcontroller for the up/down counters and the display, but the rest of the circuitry was still too complicated. Without any further recourse, I allowed the project to whither for a while.

Then I found a marvelous circuit from Analog Devices. This device, designed to be a self contained watt-hour meter, has all the circuit functions that I would require. It amplifies and conditions the voltage and current samples, multiplies them, determines the resultant polarity, and converts it to a frequency proportional to watts — all with crystal-controlled digital accuracy and only requiring a single positive supply. The

Figure 1



pulses can then be fed to the microcontroller, which will accumulate and display them. This is the solution I was looking for!

Of course, when one is counting watt-hours, one is counting energy, whereas when one is counting amp-hours, one is counting charge — quite a different thing. The trick to make the thing work is to feed in a very accurate voltage, which then becomes just another constant factor in the device's voltage to frequency conversion ratio. By carefully selecting this factor and adjusting the count ratio by the microcontroller, I had achieved my intended result.

Circuit Description

As shown in the schematic of Figure 1, the battery current is sampled with a low value shunt resistor, Rsh. More on how to choose the value of Rsh later. After some filtering via R1, R2, C1, and C2, the voltage is applied to the current sense input pins of U1.

The voltage sense inputs are "fooled" with a constant voltage developed by the ratio of R4 to R9. An adjustable voltage reference device, U2, is used to feed both the divider resistor and U1's reference voltage input. The voltage is adjusted to exactly 2.600 volts via P1, R7, and R8.

The device is crystal controlled for great accuracy. X1 is a common 3.5795 MHz, "color burst" crystal, the same frequency is used to drive the microprocessor. After performing all the internal computations digitally, U1 then converts them to a variable frequency which is proportional to the computed value times a ratio of the clock frequency.

The value of this ratio is set digitally via pins S1 and S0. In this instance, the circuit values and the frequency divider are set such that 2,560 pulses are output, for a full-capacity battery discharge. This is what is known in battery parlance as "1C" — one unit of battery capacity. These pulses are then fed from U1's pin 24 to a port in the microcontroller, which counts them and advances an LED every 256 pulses. U1's pin 22 is an output which produces a frequency 16 times faster than that of pin 24. It is useful to monitor battery activity.

Another important signal comes out from U1's pin 20 to the microcontroller. It indicates the battery's current flow polarity, or whether it is discharging or charging. This is important because it not only tells the microcontroller to count down or to count up, but also, when counting up, that 320 pulses, instead of 256, are required to advance an LED count.

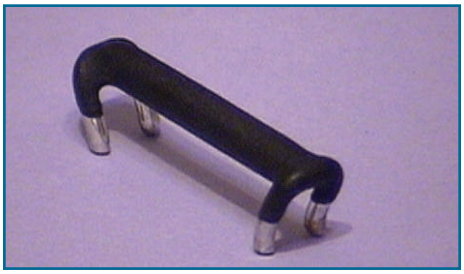
The reason for doing so is that it takes more charging energy to recover what was lost during discharge. To account for that, we must have a longer count during the charge period. I have experimentally determined that for a sealed lead-acid battery this amounts to about a 25% loss, which more or less agrees with the battery manufacturer's specification of 30%. Of course, you may change this ratio easily by adjusting the microcontroller's code. (Both the ASM source code and the compiled HEX image may be downloaded from the *SERVO MAGAZINE* website, **www.servomagazine.com**).

The display business of the project is a 10-LED bargraph, which is driven directly by the microprocessor, and current limited by resistor networks R11 and R12. Each LED segment will light up sequentially, as the battery is charged or discharged.

If the supply voltage is interrupted, the battery state information could be lost. Therefore, it is imperative that the last state is stored in the microprocessor's internal nonvolatile EEPROM.

Input port RB0 is configured as an input which is flagged by the voltage regulator's reset output. In addition, this reset flag enables or disables Q1, a Darlington transistor. This feeds the positive voltage to the LED display. When the reset flag is low, the transis-

Photo 2
Shunt Resistor



tor is disabled, and all of the LEDs will be dark. This helps preserve current such that the processor has enough time to perform the save state routine.

Finally, U3 provides a regulated +5 volts for the project. It is a low-dropout device which will maintain regulation even in the most extreme conditions. Since it was designed for automotive applications — where reverse battery and voltage transients are common occurrences — it has extensive protection against mishaps. It also has a reset output, which is used for the purposes described above.

Circuit Construction

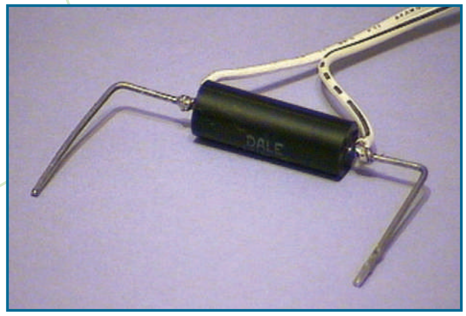
The circuit values shown in the schematic are useful for any lead-acid battery. The only consideration is that I performed my tests on a battery capacity of 7 AH. This means that the 20 milliohm shunt resistor will drop 140 millivolts at the rated current. Since U1's current amplifier input overloads at 440 milivolts, this essentially means that the battery may supply slightly over three times the rated current and the circuit will still measure it accurately. This is important especially for motor drive circuits, as a stalled or overloaded motor consumes several times its rated current while the shaft is locked (as in starting under load).

Input voltage range is from 5.6 to 24 volts, which means that 5 to 10 lead-acid cells may be used. The six cell, nominal 12 volt battery is extremely popular due to its automotive origins, and is ideally suited for this project. On the other hand, a three cell, 6 volt nominal battery, when discharged, would provide too little voltage to allow the 5 volt regulator to operate properly. In this instance, a switchmode regulator would be required.

A suitable SEPIC-switchmode regulator, which operates on battery voltages above and below its output voltage, appeared in the April 1999 issue of *Nuts & Volts*.

If a different battery capacity is required, the only consideration is to calculate the shunt resistor such that it will drop 140 millivolts at the rated current "C." Speaking of the shunt resistor, it is crucial, due to the low ohmic values involved, that a 4-wire device is employed. On a normal 2-wire resistor, the lead and junction resistance, although minute, will still introduce significant errors.

Photo 3
Homemade Shunt



Some current-sense resistors are specifically designed for such a task, as shown in Photo 2. If you are unable to procure one, you may still rig your own 4-wire resistor as shown in Photo 3.

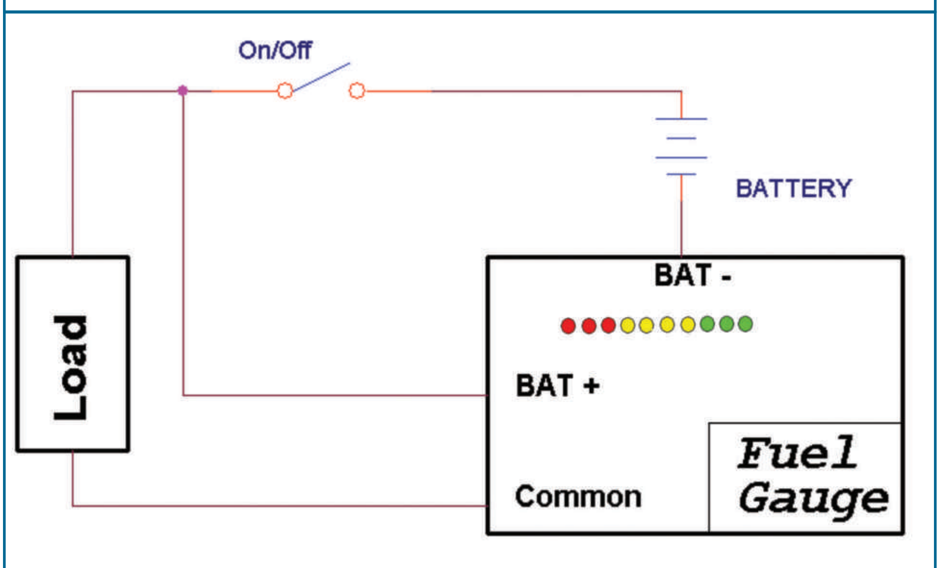
A normal, low value, 2-wire device has some pigtails attached as close as possible to the resistor's body. Thus, wire and bonding pad resistance errors are avoided. Of course, always calculate the resistor's power dissipation: P = I * I * R.

I've specified several precision resistors in the circuit. The most important are R4 and R9, which set the "dummy" voltage. If you may obtain 0.5% or 0.1% tolerance resistors, then essentially the project's accuracy is set by the shunt resistor accuracy. However, if you are cost conscious, a 1% tolerance resistor may be used on those locations.

The only adjustment required is to ensure that the reference voltage is set as closely to 2.600 volts as possible. P1 is used for that purpose. Use a 4-1/2 digit multimeter, if available, for calibration.

It is essential that you do not change the crystal frequency, as U1's frequency conversion is directly proportional to it.

Figure 2



Parts List

Resistors	Unless noted, all 1/8 W, 5%
R1, R2, R3	1 K
R4	1 K, 1%
R5	10 W
R6	2.2 K
R7	390, 1%
R8	20.5 K, 1%
R9	7.32 K, 1%
R10	22 K
R11, R12	5 X 270 ohm network
P1	1 K, cermet
Rsh	see text
Capacitors	**Unless noted, use the lowest voltage available for the rated capacitance**
C1 - C4	0.033 mF, 20% X7R ceramic
C8, C10, C14	100 mF elecrolyctic
Semiconductors	
U1	AD7755 power meter IC, Analog Devices
U2	TL431 voltage reference, Texas Instruments
U3	LM2925 regulator with reset, National
U4	PIC16F84 microcontroller, Microchip
U5	10-LED bargraph
Q1	MPSA28 Darlington NPN
X1	3.5795 MHz crystal

Figure 2 shows the wiring connections to interface the battery fuel gauge to your application. The specified microcontroller has the necessary flash-RAM, which will keep the current battery state if it is turned off.

When the project is powered up, it briefly blinks all 10 LEDs to indicate that the device is up and running. Don't substitute the Darlington transistor for a garden variety NPN device, as it will not have the required gain.

As mentioned previously, this circuit measures first-order charge effects exclusively, which essentially means charge/discharge currents. Self-discharge and temperature effects are not considered in this simple project, but could be incorporated fairly easily.

Therefore, this constraint makes this project to be less accurate in applications where the battery is seldom or infrequently used. Your battery application should be used at least once a month, to make self discharge errors negligible.

Night of the living Hexapod

Part I

This autonomous robotic lifeform
is the perfect platform
to carry out your own experiments
and explore the world of Robotics!

WALKING ROBOTS:

THEY ARE ONE OF THE MOST INTERESTING RESULTS OF TODAY'S ADVANCED TECHNOLOGY. WITH THE POPULARITY OF MICROCHIP PIC MICROCONTROLLERS AND THE DEVELOPMENT OF COMPILERS TO SUPPORT THEM, BUILDING MOBILE ROBOTS WITH "BRAINS ON BOARD" HAS NEVER BEEN EASIER.

by Karl Williams

THE LIST — HEXAPOD ROBOT

PART	DESCRIPTION
SEMICONDUCTORS	
☐ U1	78L05 5-volt regulator
☐ U2	PIC 16F819 microcontroller
☐ Q1 - Q4	2N4401 NPN general purpose
☐ Q5 - Q8	2N4403 PNP general purpose
☐ D1, D2	Light emitting diodes
☐ D3 – D10	1N4148 diodes
RESISTORS	
☐ R1	
☐ R2, R3	4.55K potentiometer with a 1/8" diameter and 5/8" length shaft
☐ R4,R5	
CAPACITORS	
☐ C1-C5	0.1µ fd
☐ C6	200 pF
MISCELLANEOUS	
☐ Sharp GP2D12 module	Sharp infrared sensor module
☐ PZ1	Piezo speaker
☐ SW1	On/off toggle switch SPST
☐ BT1	3V battery holder (2 x AA)
☐ M1, M2	Tamiya dual motor gearbox – item 70097
☐ Connectors	2 connector female header 2.5 mm spacing
☐ JP1-JP10	2 post male header connector 2.5 mm spacing
☐ Connectors	3 connector female header 2.5 mm spacing
☐ JP11-JP14	3 post male header connector 2.5 mm spacing
☐ Ribbon wire	3 strand
☐ Ribbon wire	2 strand
☐ Hookup wire	18 gauge plastic coated
☐ Standoffs	2-56 x 1 1/4-inch
☐ Machine screws for	2-56 x 1/4-inch
standoffs	6/32 x 1-inch
☐ Machine screws	6/32 x 1/2-inch
☐ Machine screws	6/32
☐ Locking nuts	6/32
☐ Nylon washers	1/4 x 5/16-inch
☐ Nylon spacers	2-56 x 1/4-inch
☐ Machine screws	2-56
☐ Nuts	9 volt battery connector - PCB mount
☐ BT2	Non slip rubber
☐ Rubber feet	1/8-inch diameter
☐ Heat shrink tubing	Available at www.thinkbotics.com
☐ Printed circuit board	9 volt
☐ Controller board battery	1.5 volt type 'AA'
☐ Motor supply batteries	
ALUMINUM	
☐ Aluminum stock	1/2 x 1/8-inch
☐ Aluminum stock	1/4 x 1/4-inch
☐ Flat aluminum stock	1/16-inch thick

In the past, a big problem with mobile robots was that they were often tethered to their computers. The support electronics, microprocessors, and batteries were too large to carry onboard. The robots, like the computers that controlled them, were large, power hungry machines. Keeping the robots close to their host computers placed limitations on the environments that the robots could operate in and the real world experiments that could be carried out.

The robots were restricted to university laboratories, out of the hands of the electronics experimenters and enthusiasts.

That has all changed ...

Building the hexapod robot presented in Figure 1 will allow you to experience the excitement of creating your own artificial lifeform that can walk, explore, and react to its environment.

This hexapod robot is unique because it uses two DC gear motors contained in one unit to power the six legs. One gear motor drives the three legs on the left side of the robot's body and the other gear motor drives the three legs on the right side.

The robots' body and legs are constructed with standard aluminum pieces and fasteners that are available at most hardware stores.

The robot controller circuit is designed around the PIC 16F819, which contains 16 I/O pins and five 12-bit analog-to-digital converters. Another feature of this device is a software selectable internal oscillator that can be configured to run between 2 and 8 MHz. With the sophistication of the new PIC microcontrollers, the robot controller board uses fewer parts than would have been required a couple of years ago.

The instructions for building and programming the robot will be divided into two articles. The first article will deal with the mechanical aspect of the construction and the second part will deal with the electronics, programming, walking gaits and experiments.

Complete list of parts necessary to build the robot.

Step 1. Cut Out Base

The first step in creating the robot is to construct the aluminum base to which the legs, electronics, gearmotors, batteries, and the controller circuit board will be fastened.

This will require the use of a hacksaw (or a band saw with a metal cutting blade), a power drill, table vise and a metal file. Cut and drill a piece of 1/16-inch thick flat aluminum (4-1/2 inches wide x 6 inches long) to the dimensions shown in Figure 2.

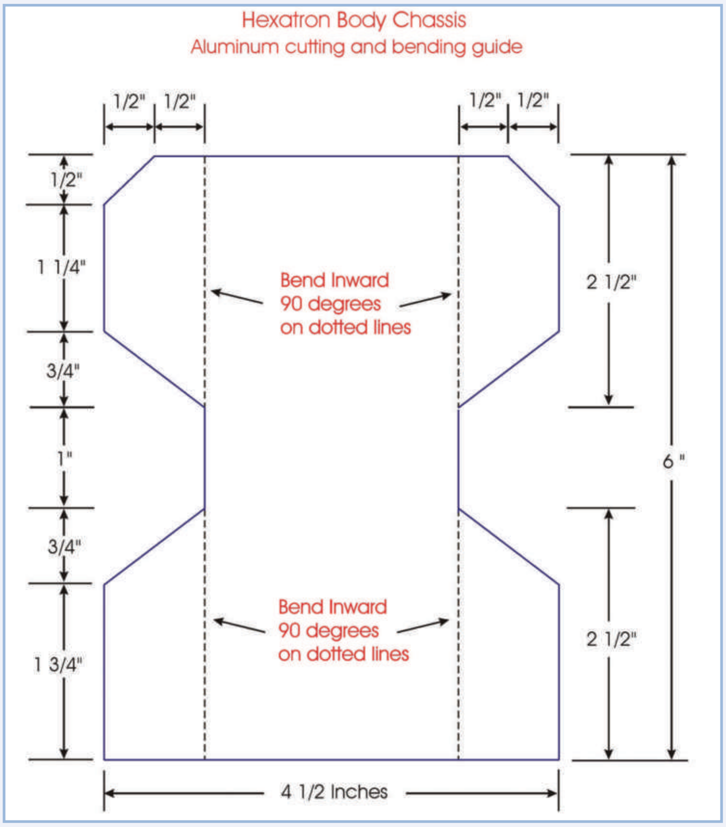


Figure 2
Body chassis cutting and bending diagram.

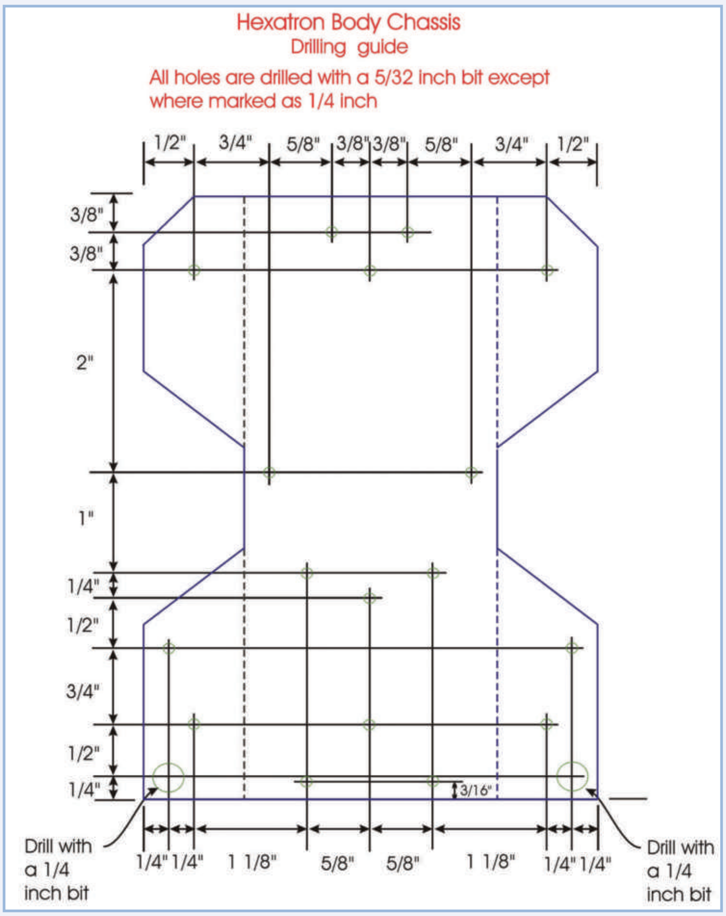


Figure 3
Body chassis drilling diagram.

Step 2. Drill Mounting Holes

Drill all of the holes indicated in Figure 3 using a 5/32-inch drill bit except for the two holes that are marked as being drilled with a 1/4-inch bit. Use a metal file to smooth the edges and remove any burs from the drill holes. (Bend the aluminum inward at 90-degree angles according to the bending lines shown in Figure 2.) Use a bench vise or the edge of a table to bend the pieces.

Step 3. Locate Battery Packs

Locate the two 3-volt battery packs (2 x AA) and fasten them to the bottom of the body chassis with two 2-56 by 1/4-inch machine screws and nuts. (Use Figures 4 and 5 as guides when attaching the battery packs to the body chassis.)

Thumbnail views

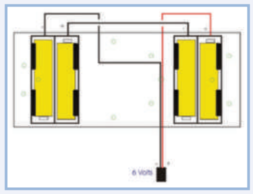


Fig. 4

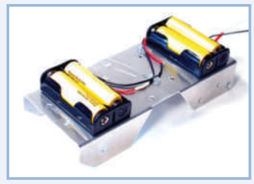


Fig. 5

Step 4. Wire Them Up!

Next, wire the battery packs together in series to achieve a 6-volt output by following the wiring guide shown in Figure 4. (Note that the 6-volt output wires are fed through the hole in the bottom of the chassis up to the top side as indicated in Figure 4.)

If the lengths of the wires, measured from the top of the robot chassis, are not at least five inches long, add some extension wire.

Solder a two connector female header to the end of the 6-volt output wires. Insulate each of the connections with a 1/2-inch piece of heat shrink tubing.

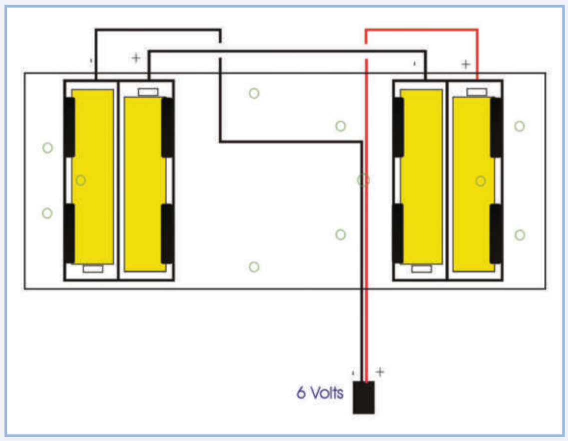


Figure 4
Battery wiring and power lead routing.

At this point in the construction, the body chassis with the two 3-volt (2 x AA) battery packs fastened to the underside should look like the one shown in Figure 6.

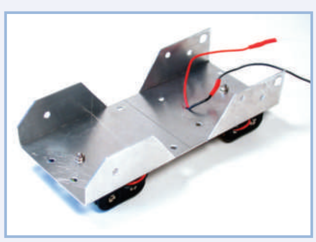


Figure 6

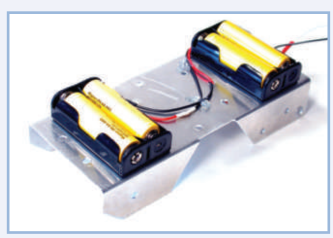


Figure 5
Underside view of the chassis.

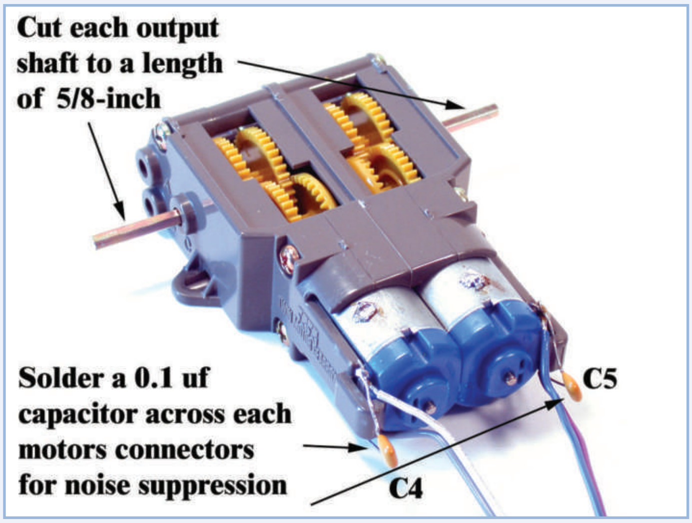


Figure 7
Tamiya dual motor gearbox configuration.

Step 5. Gear Up!

Next, assemble the Tamiya twin motor gearbox using the instructions (supplied with the motor kit) for a gear ratio of 203:1.

Apply the supplied lubrication to the gears so that they mesh smoothly and run quietly when the motors are in operation. Use a hacksaw to cut each of the motor output shafts to a length of 5/8 inch as indicated in Figure 7.

Cut two pieces of 2-strand connector wire to a length of eight inches each. On one end of each of the cables, solder a two connector female header and use heat shrink tubing to protect the solder joints. Solder the first wire of the first connector cable to one of the power terminals of the left motor.

Solder the second wire of the first connector cable to the remaining power terminal of the left motor. Repeat this same procedure for the second connector cable and the right motor. Solder a 0.1 µF capacitor (C4 and C5) across the terminals of each motor, shown in Figure 7, to reduce RF interference.

Step 6. Get Some Feedback

Locate the two 4.5 K potentiometers and attach a four inch long, 3-strand connector wire to each one. Solder a 3-connector female header to the other end of each wire as shown in Figure 8.

Figure 8
Potentiometers with connector wires attached.

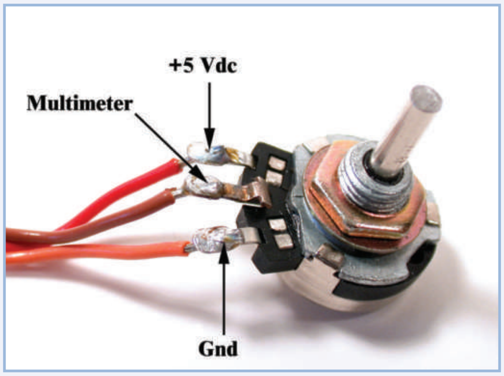


Figure 9
Procedure to center the potentiometer shafts.

Step 7. Insulate and Calibrate

Insulate each of the connections with a 1/2-inch piece of heat shrink tubing. Before the legs are attached to the chassis, each of the potentiometer shafts must be set to their middle positions. This is accomplished by the procedure that follows.

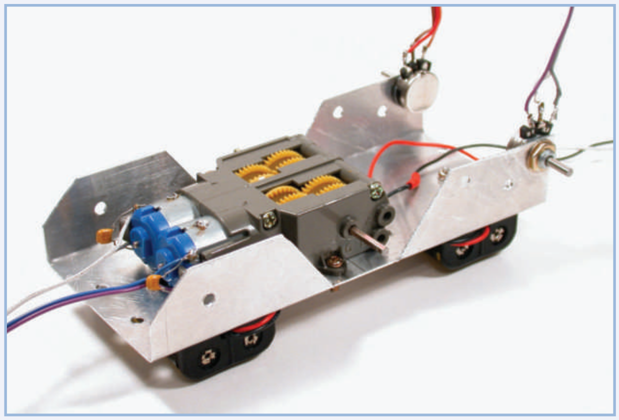
Use Figure 9 as a guide to attach a 5-volt DC supply to the outer terminals of the first potentiometer. Attach the leads of a multimeter to the middle terminal and ground so that the voltage can be read. Turn the potentiometer shaft until you get a reading of 2.5 volts. Calibrate the second potentiometer using the same procedure.

Step 8. Build Up the Chassis

Now that the gear-motors and potentiometers are wired, it's time to attach them to the body chassis. Position the gearmotor as shown in Figure 10, and secure it to the chassis using the two machine screws and nuts that came with the motor kit.

Mount each of the potentiometers in the 1/4-inch holes at the back of the robot chassis as shown in Figure 10. Make sure that the nuts are secured tightly so that the potentiometers do not move out of position when the robot is in operation.

Figure 10
Twin motor gearbox and potentiometers attached to the chassis.



Constructing The Legs And Motor Shaft Mounts

Step 9. Give It Legs

Using the 1/2-inch by 1/8-inch aluminum stock, cut and drill six leg pieces labeled A, four outer leg linkage pieces labeled B, two middle leg linkage pieces labeled C, and two leg sensor linkage pieces labeled D according to the dimensions shown in Figure 11. Use a 5/32-inch bit to drill the holes.

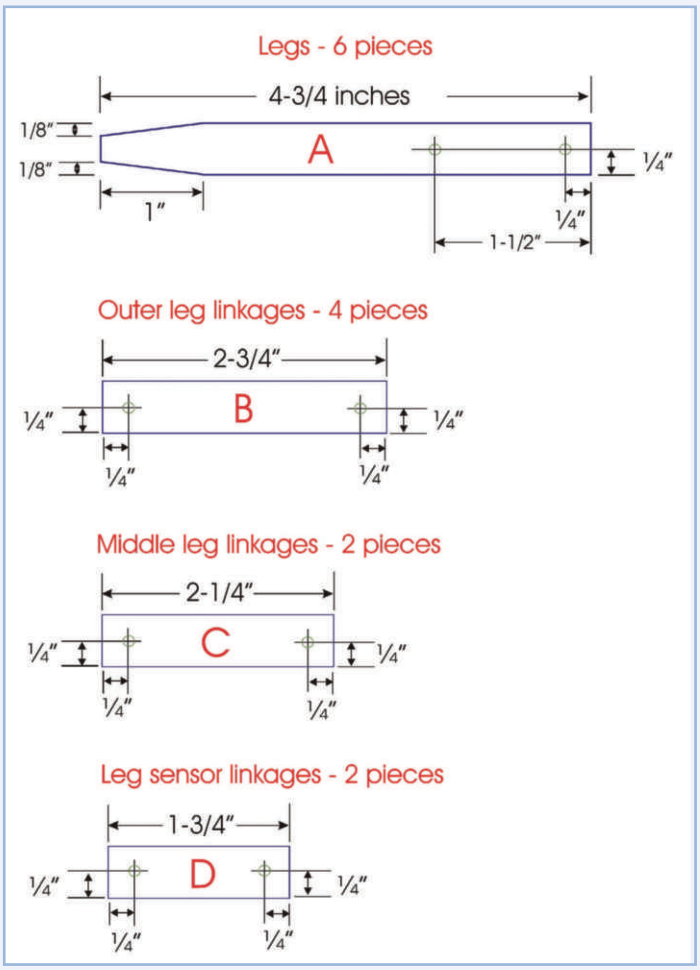


Figure 11
Cutting and drilling guide for the leg and linkage pieces.

Step 10. Shaft Mounts

Fabricate the motor output shaft mounts and potentiometer shaft mounts using 1/4-inch x 1/4-inch aluminum square stock according to the dimensions shown in Figure 12.

The motor shaft mounts are labeled as parts E and the potentiometer shaft mounts are labeled as parts F.

When the pieces are finished, thread a 6-32 x 3/16-inch set screw in each of the holes that were threaded with the 6-32 tap.

Figure 13 shows a completed motor shaft mount and potentiometer shaft mount.

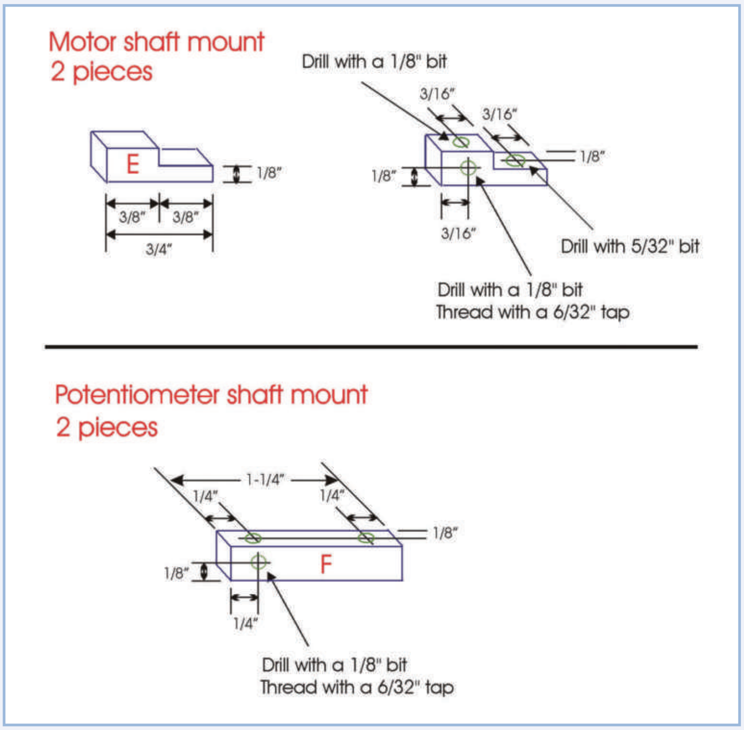


Figure 12
Motor shaft mount and potentiometer shaft mount fabrication diagram.

Assembling The Legs

Now that the individual pieces for the legs and linkages have been constructed, it's time to put them all together to form the mechanical part of the walking machine. Refer to Figures 14 and 15 when assembling the legs.

Step 11. Start by attaching one of the motor shaft mount pieces labeled E to the shaft of the right motor with the flat edge facing away from the motor.

Make sure that the end of the shaft is flush with the face of the motor linkage and secure it in place by tightening the set screw.

Step 12. Attach piece A to the motor mount with a 6-32 x 1-inch machine screw with a nylon washer separating the two.

Step 13. On the same machine screw, place another washer, then linkage piece B, then a washer, and then another linkage piece B.

Secure all of the pieces together with a 6-32 locking nut.

Step 14. Attach two leg pieces A and linkage piece C to the chassis at the locations shown in Figures 14 and 15.

Step 15. Attach potentiometer shaft mount F to the potentiometer shaft, but do not fasten the set screw at this time.

Step 16. Attach linkage piece D to piece F by placing a #6 nylon washer between the pieces and secure with a 6-32 x 1-inch machine screw and locking nut.

Step 17. Starting from the front of the robot, attach leg piece A to linkage B with a 6-32 x 1-inch machine screw and locking nut.

Separate the pieces with a 6-32 x 5/16-inch plastic spacer.

Do the same with middle leg piece A and linkage piece C but add two nylon washers along with the 6-32 x 5/16-inch plastic spacer.

Step 18. Attach the back leg piece A to pieces D and B, with a 6-32 x 5/16-inch plastic spacer between pieces A and D and a nylon washer between pieces D and B.

Tighten all of the locking nuts with enough pressure to hold the parts in place, but still allow them to move freely without any resistance.

Step 19. Perform the above procedure for the left side of the robot.

Step 20. When everything is in place, use your finger to manually rotate the gearboxes so that the middle leg on each side is in the downward position and perpendicular to the chassis.

Step 21. Tighten the set screw on both of the potentiometer shaft mount pieces F. If you suspect that the potentiometer shafts have been moved from their middle positions, then re-calibrate each one before tightening the set screw (refer to Step 7).

When the mechanics are complete, add a rubber foot to the end of each leg. This will give the feet more friction and help to grip when the robot is walking on slippery or uneven surfaces.

Head and Infrared Sensor Mount

Step 22. Get Ahead

Fabricate the robot's head using a 1 3/4 x 3 1/2-inch piece of flat 1/16-inch thick aluminum. Follow the cutting, drilling, and bending diagram shown in Figure 16.

Step 23. Sharp IR Detector

Locate the Sharp IR detector module and secure it to the head section with the mounting machine screws and nuts that came with it. See Figure 17 for orientation.

Step 24. Recapitate

Attach the head to the body using two 6-32 x 1/2-inch machine screws and locking nuts as shown in Figure 17.

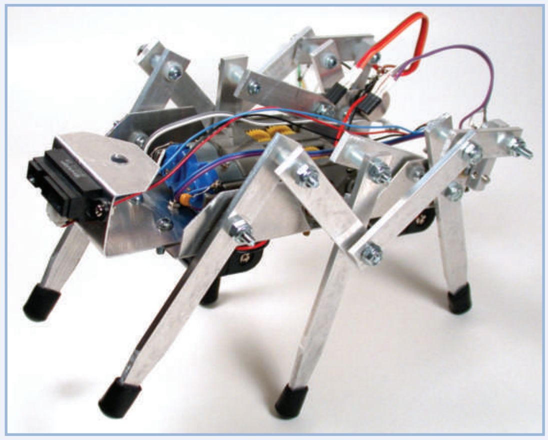


Figure 17
Finished mechanical assembly of the robot.

Figure 16
Cutting, drilling, and bending guide for the robot's head section.

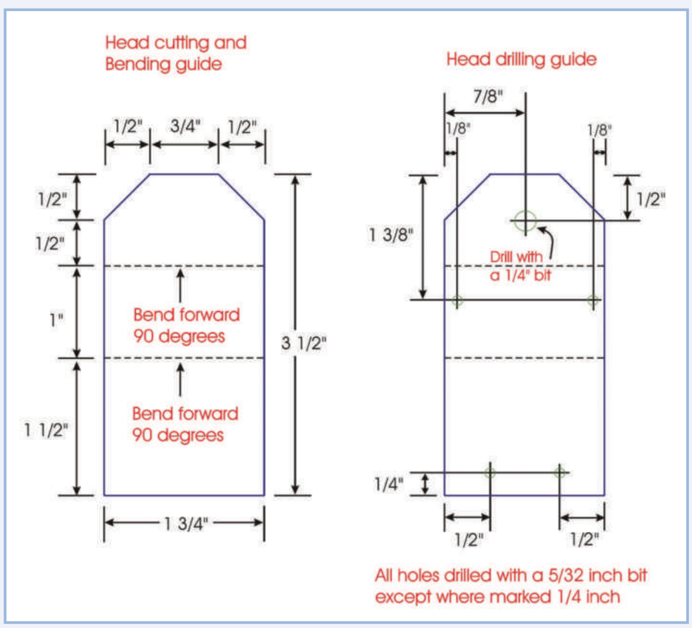
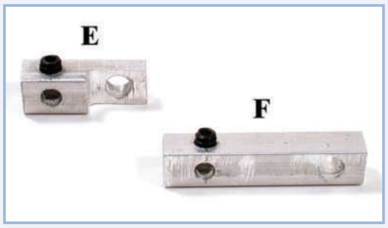


Figure 13 Completed motor and potentiometer shaft mounts.



The mechanics and sensors of the walking robot are now assembled into place.

All that is needed to bring the robot to life are the electronics and some microcontroller programming.

In the next part of the Hexatron series, the electronics, wiring, sensors (infrared and leg position) and programming of the PIC 16F819 microcontroller will be covered.

Visit the author's website for more information about the project (**www.thinkbotics.com**).

AUTHOR'S BIO

Karl P. Williams is the author of two robotics books titles *Insectronics: Build Your Own Six Legged Walking Robot* (ISBN 0-07-141241-7) and *Amphibionics: Build Your Own Biologically Inspired Robots* (ISBN 0-07-141245-x), both published by McGraw-Hill.

He hosts a robotics website at (**http://home.golden.net/~kpwillia**) and can be contacted through **www.thinkbotics.com**

Figure 14 Leg and linkage parts assembly diagram — outside view.

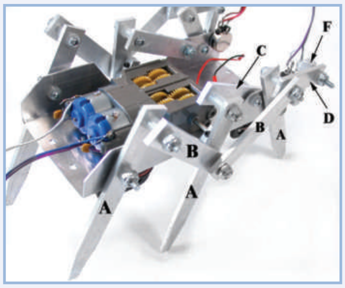
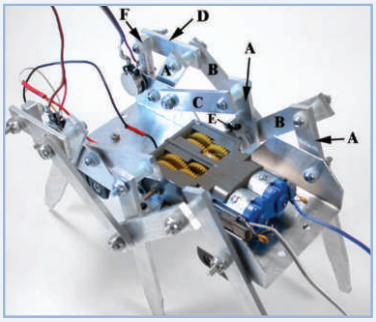


Figure 15 Leg and linkage parts assembly diagram — inside view.



Build A One-Pound Fighting Robot PART 2

Put the Finishing Touches on Your Mini Robot!

by Patrick Campbell

Part 1 of my article ran in the *Amateur Robotics Supplement #2,* back in August of 2002, where I explained how to design a SOZBOT — from laying out the drivetrain to architecting an effective weapon. This part finishes off the project and brings all the subsystems together to form a fierce 16 ounce fighting machine, which I named *Demonic.*

Figure 1 shows an exploded view of the design and attached is a rough parts list. With all the purchased parts in hand, I only need to make a few parts — the chassis top and bottom out of carbon fiber sheet, the weapon blade and two mounting plates for the weapon out of aluminum, and some short shafts. First, we'll start out with the carbon fiber parts.

PARTS LIST

ITEM	QTY	PART NUMBER	DESCRIPTION
1	2	SOZBOTS P/N BM3MM	Dual Bearing Mount
2	2	SOZBOTS P/N MMGH01	Motor Mount
3	1	SOZBOTS P/N SOZDSC-M	SOZBOT Speed Controller
4	1	Custom Fabrication	Bottom Chassis
5	1	SOZBOTS P/N RCRXFM5	Radio Receiver
6	1	Custom Fabrication	Top Chassis
7	1	SOZBOTS	Weapon Motor
8	1	10 Tooth Gear	Weapon Drive Pinion
9	2	7.2V 1000 mAhr	LiPoly Battery
10	1	50 Tooth Gear	Weapon Disc Gear
11	1	Custom Fabrication	Weapon Left Mount
12	2	SOZBOTS P/N BE3MMF	Flanged 3mm Bearing
13	1	Custom Fabrication	Weapon Disc
14	1	Custom Fabrication	Weapon Right Mount
15	1	SWITCH	Switch
16	1	Custom Fabrication	Switch Block
17	4	SOZBOTS P/N W50T30D	50mm Wheels
18	2	SOZBOTS P/N GH27MOT	Gearmotor
19	4	SOZBOTS P/N CHS16HEX	Chain Sprocket

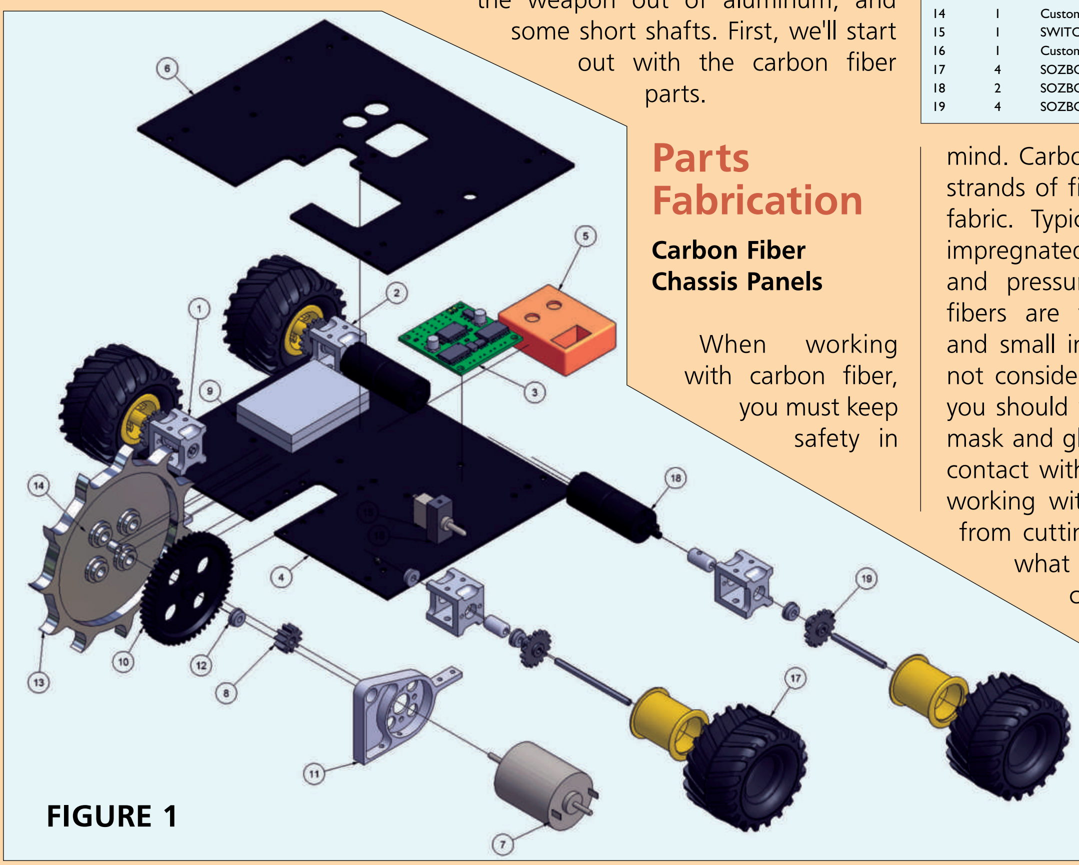


FIGURE 1

Parts Fabrication

Carbon Fiber Chassis Panels

When working with carbon fiber, you must keep safety in mind. Carbon fiber is made by taking strands of fiber and weaving it into a fabric. Typically, the fabric is epoxy impregnated and cured under heat and pressure in an autoclave. The fibers are very strong, lightweight, and small in diameter. Although it is not considered a hazardous material, you should wear safety goggles, dust mask and gloves to avoid coming into contact with the fibers when you are working with it. The dust generated from cutting, sanding and drilling is what you don't want to get in contact with.

In my case, I mounted the 0.030-inch thick carbon fiber panel in my CNC milling machine and cut out the shape I designed in my CAD program. I realize most people

don't have access to a CNC machine, but carbon can be cut like most other materials. It can be cut with a hack saw, Dremel, router, shear, snips and even by scoring with a sharp knife if it's thin enough. It's tough stuff and tends to wear down your tools, so use sharp carbide or diamond tipped blades if possible. I then drilled clearance holes for all the screws. After cutting and drilling, I used a file and sandpaper to smooth off the cut edges. This ensures that the finished part is safe to handle without gloves and the edges end up nice and smooth. Before I removed my gloves and dust mask, I washed the parts in cold water.

If you don't want to work with carbon fiber, you can choose a variety of materials from foamed PVC sheet to sheet metal. The appeal of carbon fiber is its high stiffness, high strength, and light weight, but there are other materials that can do the same job at increased weight.

Aluminum Blade and Mounts

These parts were all cut from 1/4-inch aluminum on my CNC milling machine. Although the blade is a fairly difficult part to fabricate without such machinery, you can go down to your local hardware store and find a small cutting blade of the same diameter and adapt it accordingly. The mounts are a bit tougher to fabricate, but your challenge will be to build parts with the same functionality with the tools you have on hand.

The weapon blade uses 3mm bearings which are pressed into the uprights. You can use a low friction plastic, like Delrin (acetal), and you won't need to worry about bearings. Delrin is a good material choice for the uprights as it is easy to work with and very durable. The weapon shaft is 1/8-inch diameter with the ends turned down to 3mm (0.118-inch) to fit into the bearings. The step on each end of the shaft captures the shaft in the bearings. I used flanged bearings to capture them between the uprights. The shaft is pressed into the weapon blade and I still used some shaft spacers to keep the blade centered between the uprights.

The mounts are tapped #4-40 on the bottom. It is attached to the carbon fiber with small button head screws. One of the holes is on center with the motor, so by using a long enough screw, it bottoms out on the motor, retaining it in the upright.

Wheel Axles

The wheel axels need to be cut to the correct length. This is done with a hacksaw, and then filed to take off the sharp edges.

Robot Assembly

All the parts are ready to go — now it's time to assemble!

Rear Motor and Wheel Assemblies

First, we insert the flanged bearing into the mount with the flange on the inside of the block. Then we take the shaft adapter with the shaft pressed in it and insert it into the bearing. Then we mount and install the motor with the two screws and lock down the setscrew on the shaft adapter to the motor output shaft. Press on the 16-tooth chain sprocket to the shaft, and then press on the wheel and the assembly is complete.

Front Wheel Assemblies

Insert the two bearings into the mount with the flanges on the inside of the block, and then insert the shaft into the two bearings with the supplied spacer between the bearings. The setscrew on the spacer will hold the shaft in place, so adjust it to determine how much shaft overhang you need. Now press the chain sprocket and the wheel on the shaft. If you don't want the wheel to pop off in battle, you might want to use a drop of superglue.

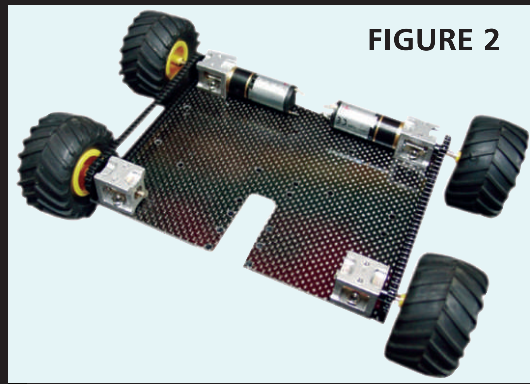


FIGURE 2

Mounting Drive Train to Chassis

Take all four assemblies and screw them to the bottom chassis using some #4-40 x 3/16 button head screws. Align the sprockets and run the chain over them. The chain is easy to work with — just use your fingernails to take links apart and put them back together again. Figure 2 shows the drive train mounted to the bottom chassis.

Weapon Assembly

Attach the gear to the saw blade and insert the shaft through the bore. It's important to keep the gear cen-

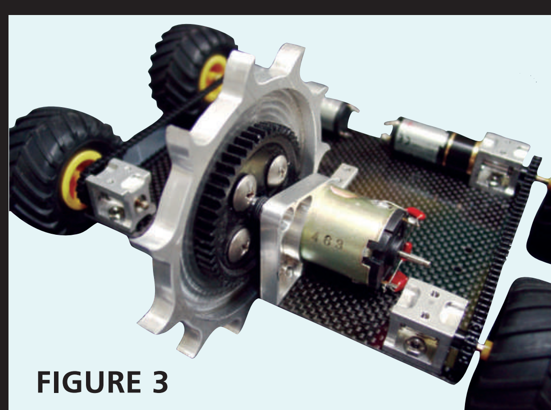


FIGURE 3

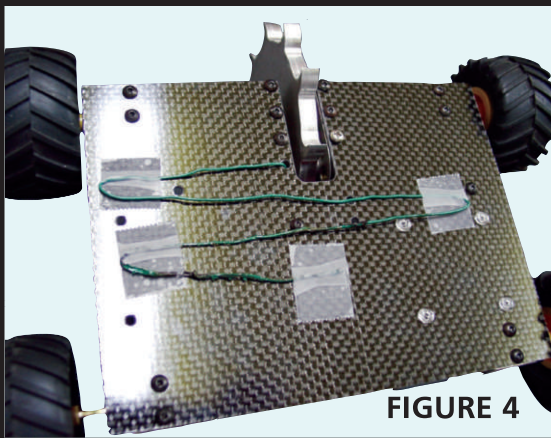


FIGURE 4

tered as much as possible to the center bore of the blade to ensure that the gears mesh correctly. Install the bearings in each mount and then mount the motor to the left motor mount. Attach the left motor mount to the chassis, then the blade axle, and then screw in the right side to the chassis. I used fiber washers as shaft spacers to keep the blade centered on the shaft, but almost any spacer will work. Figure 3 shows the weapon assembly attached to the chassis.

Electronics

Except for the chassis top, the robot is mechanically ready. Now we'll start with the electronics.

Radio Receiver

The receiver is secured to the bottom chassis using double-sided tape. You can save weight by removing the receiver enclosure, but securing the internal electronics is a little tougher. You can still use double-sided tape, but you also have to worry about protecting the electronics.

The antenna is simply a short wire coming out of the receiver. Do not change the length of the wire and don't loop the wire on itself. Antennas are best if kept in a straight line, but for robots, the best way is to zig-zag it. Figure 4 shows the antenna taped to the bottom of the robot. Since we are typically operating the robot from no more than seven feet away, range is usually not an issue, but getting a good signal to the robot is critical.

The lightweight receivers used in these robots tend to be glitchy compared to the heavier and usually more expensive ones. The key difference is the lighter ones are single conversion and tend to be more susceptible to interference compared to dual conversion receivers.

Because of this, it's important to have good wiring and a properly mounted antenna to reduce glitching in the robot.

Speed Controller

The speed controller is the heart of the robot — it connects to the power source, to the radio receiver, and to all the motors. Because of this, there is a good deal of wiring involved with this unit. It's best to determine the mounting locations of your electronics and then figure out the shortest wire length that will work. Short wires help minimize your weight, reduce clutter, and avoid electrical noise. Twisting your power leads will also help to keep your wires neat and reduce interference. I prefer to use Teflon wire because of its high temperature characteristics. Twisting the wire is very easy — take two equal lengths of wire, clamp one end in a vise and the other in your cordless drill chuck. Run the drill while keeping tension on the wire until you get the amount of twist you are looking for.

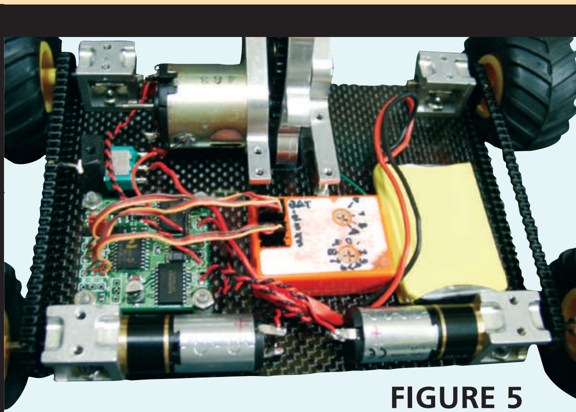


FIGURE 5

The radio receiver connections are via three wire leads that get soldered into the speed controller. The other end of the lead is a connector that plugs into the receiver. Next, the battery lead gets soldered into the board and the hot lead is cut and wired to the power switch. The power switch should always be located away from the weapon, and in a location that makes it difficult for the switch to get hit accidentally, especially by another robot. Figure 5 shows the wiring.

Battery

I was planning on using NiCd batteries, but switched to lithium polymer (LiPoly) to save weight and gain run time. For less weight, I can have about four times the battery capacity. This allows me to have just one battery in the robot that I top off between matches. I never fully drain the battery in a bout and can easily run two matches back-to-back, which can happen quite often in double elimination competitions.

LiPoly batteries have improved to the point that they can be used at high discharge rates — up to 8C. This means that my 1,000 mAH battery can continuously source 8 amps. This is just enough current to feed my drive and weapon motors. I used double-sided tape to secure the battery and I can charge it while it's in the robot. If you are using a battery that you need to remove to charge, then consider a mounting method that is easily serviceable.

There is no way to fast charge a LiPoly, but having the extra capacity

means that if you keep the robot on charge between matches, one battery should last you for the day. But, always have backups as parts can easily get damaged in a match.

Motors

To help eliminate motor noise, it's best to solder three 0.01 µF capacitors on the motors — from each brush of the motor to the motor body and between each brush. This is very important on cheap toy motors, but not always necessary on good quality motors. Remember to keep the motor leads as short as possible.

Final Assembly and Testing

Whenever you first power up the robot, keep safety in mind. I disconnect the weapon motor so that I can check the drive system and radio system first. Block the robot so its wheels don't touch the ground. Turn the radio transmitter on first and then the robot.

Once you confirm the radio and the drive are working, turn the robot off and connect the motor. Power-up again and test. If everything works, get plenty of driving practice for the next competition.

Conclusion

SOZBOTS are an excellent way to get into the sport of fighting robots. Half the fun of competing is designing and building your own robot, using your own designs.

The other half is the actual competing. It's a great way to challenge yourself to come up with a solution that is better than the other guy's as well as challenge your ability to build a durable robot that can handle the rigors of battle. And because the robots can only weigh up to one pound, the cost of building a robot and competing is far less than any other weight class.

Demonic has entered four competitions since being built, and has won 7 matches out of 15. Not quite 50%, but future improvements will give it a better chance.

A couple of improvements include replacing the aluminum blade with titanium and adding a wedge in the front to keep other robots from getting underneath and pushing him around. Good luck with your one-pounder and see you at the next SOZBOTS event! S

Sixteen OZ roBOTS!

To learn more about these SOZBOTS and their fighting events, visit www.sozbots.com.

THE TRACKER

This sensor mimics the activity of our own human eyes, which move in rapid, discrete steps to take in their surroundings.

THE TRACKER

by Thomas Scarborough

As I write, a prototype of "The Tracker" watches my every move with attention as keen as that of a dog expecting a treat — and every time I leave my seat, it turns its head to follow my movements around the room.

The Tracker is a robotic head which employs two electronic "eyes," each of which is extremely sensitive to moving shadows. By adding some simple logic to the eyes, and a "power section" with a robust DC motor, The Tracker will turn a head to track the motion of a person walking by.

Sophisticated circuitry is normally used to track motion in this way. The Tracker, however, uses cheap and common components throughout, in what is a relatively simple circuit. If its left eye detects motion, its head rotates left. If its right eye detects motion, its head rotates right. If both eyes detect motion simultaneously, it simply "stays put."

The Eyes

The success of The Tracker as a design comes down, in the final analysis, to its eyes. These need to meet two important criteria.

First, they need to be very responsive if they are to pick up moving shadows at any distance. Second, they need to auto-adjust to ambient light, so as to respond to a fairly wide range of lighting conditions as they scan a scene.

On the second count, The Tracker uses what is called a "passive" detection system. This means that it does not use a fixed light source which is integral to the design, but responds to relative fluctuations in light level.

I chose "shadow sensors" for the eyes (sometimes called "light sentinels"), since in certain situations these have important advantages over infrared or ultrasound.

First, both infrared and ultrasound are unable to sense motion through glass. Second, infrared is unable to sense objects which are thermally indistinguishable from their background. The Tracker, through its use of shadow sensors, will track shoppers through a store-front window or detect "thermally neutral" motion, such as luggage moving on a conveyer belt. These features are described in greater detail below.

Block Diagram

The block diagram in Figure 1 gives a simplified representation of how one of The Tracker's eyes works. Note that several components are omitted from this diagram.

A light dependent resistor (LDR) forms the lower arm of a potential divider, and this presents a potential at point X of approximately half the supply voltage. This potential fluctuates with changing light levels (i.e., shadows in clothing).

The potential at point X is then presented simultaneously to the inputs of two bilateral switches. An astable oscillator with an integral divider alternately switches the bilateral switches at several Hertz, so that the two capacitors at the inputs are alternately charged.

Since the resistance of the bilateral switches in the off state is very high and the input impedance of the op-amp comparator is very high, the charge on the capacitors is "trapped" in the spaces between the bilateral switches and the comparator. These are referred to as sample-and-hold circuits.

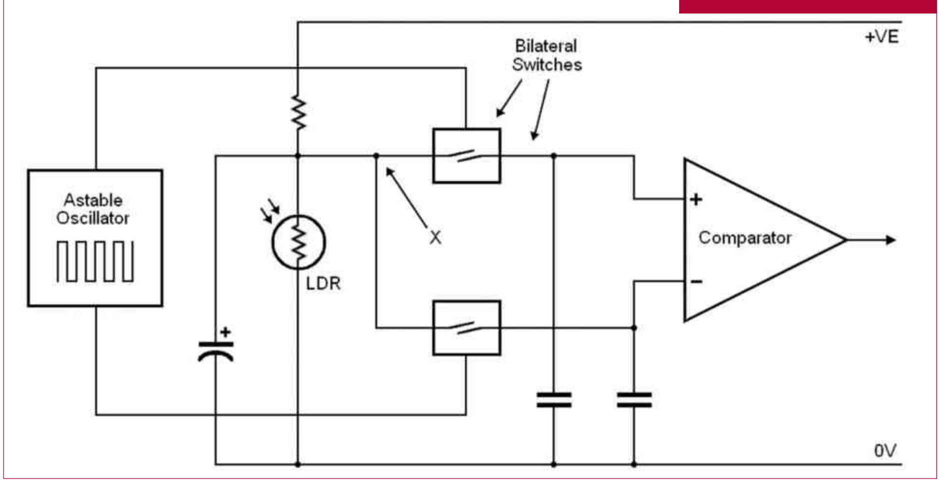
As the light level rises and falls, the charge (that is, the potential) at the comparator's inverting input exceeds that at the non-inverting input and the comparator's output goes low, thus triggering a monostable timer. The effect is that the eye compares light level over time.

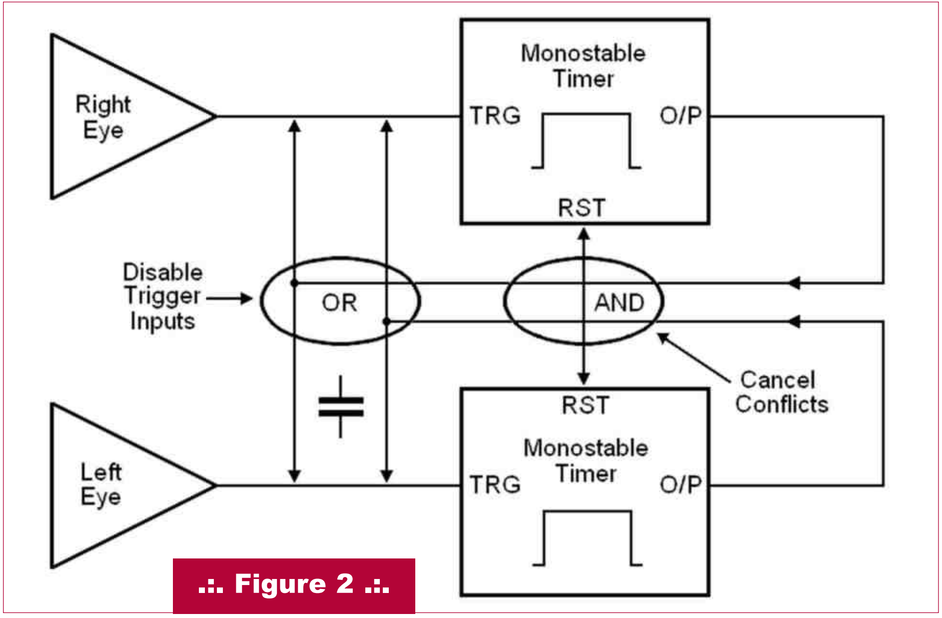
One of the toughest problems to crack with the present circuit was that of the eye's response under AC lighting. This is because the circuit needs to distinguish between quick and subtle shifts in light level on the one hand, and the flicker of AC lighting on the other. This problem was effectively solved for incandescent lighting, although harsher lighting (i.e., sodium lamps) could negatively affect sensitivity.

The core of the solution lies in a carefully chosen capacitor (Figure 1) wired in parallel with the LDR, which smoothes out ripples at point X. While this reduces the overall sensitivity of the eye by about one-third, it also reduces AC ripple by about 90%. In conjunction with other select component values in the "eyes section," this brings about a very significant improvement in response.

The "sure bet" range of The Tracker under AC incandescent lighting should be more than eight feet — and about twice this under natural lighting. However, with careful adjustment and tweaking, as described below, it should be possible to extend this to the full potential range of the eyes. These are

.:. Figure 1 .:.





.:. Figure 2 .:.

capable of spotting a person walking under natural lighting at 60 feet, or under AC incandescent lighting at 20 feet, without lenses.

Motor "Blanking"

The block diagram in Figure 2 gives a more simplified overview of The Tracker's logic, or brain.

The Tracker's brain is small, performing only an AND operation and an OR operation on the two monostable timer's outputs, with the help of four bilateral switches.

If either eye triggers individually (which is OR), the other eye is instantly disabled. In fact, both eyes are disabled to prevent any interference from the power section and motor, which draw a heavy current and send ripples throughout the circuit. The eyes are disabled as long as the motor is energized, and continue to be disabled for as long as a timing capacitor determines (C12 in the full circuit diagram). This "blanks" the action of the motor, and gives the circuit sufficient time to compose itself after each movement of The Tracker's neck.

This blanking has more than one purpose. First, if there was no blanking, the eyes would see motion all the time as The Tracker turned its neck. The circuit blanks out the motion of a spinning world around it, as well as any physical vibrations that might be caused by the turning of its neck.

Second, if both monostable timers trigger simultaneously (which is AND), both timers are instantly reset. This removes any conflict between the two eyes (and thus any conflict at the motor), and causes The Tracker to wait for the next trigger pulse from either eye.

Circuit Detail

Much of this circuit (see Figure 3) represents standard electronics, and requires little explanation. At the same time, there are a few critical features which I shall highlight here.

Most importantly, the circuit needs to combine the extreme sensitivity of the eyes with the heavy switching of the power section and motor. Therefore it uses supply decoupling capacitors throughout. (In the interest of simplicity, these are not reflected in the full circuit diagram).

The circuit also uses small value capacitors — in particular C1 and C12 — and high value resistors — in particular R1, R6, and R13. C12 dispenses with a good practice parallel resistor for the sake of further discouraging ripples on the supply. Also note capacitors C8-C11, which help to stabilize the two eyes. These in particular need time to settle at switch-on.

The 4047B CMOS oscillator (U1) provides — through an internal divider — a near perfect mark-space ratio at its output pins 10 and 11, to switch bilateral switches U2a to U2d alternately.

U4 and U5 were chosen particularly for their high input impedances, which are necessary so that C4 to C7 will retain their charge. Also, they were chosen specifically for their provision of an offset-null adjustment, which is used to balance the differential input stage so that the inverting input is normally higher than the non-inverting input. Failing this, the potentials at the two inputs would be too close for comfort, and might or might not trigger the ICs.

While LDRs have slower response times than other light sensitive devices, two LDRs were chosen for this circuit because they are common devices, and may easily be interchanged with similar devices of the same family. This is not always the case with photo-transistors or photo-diodes, which have some awkward relatives. Note that if photo-diodes are used, the cathodes would normally be wired to points A and C in the circuit. An LDR is completely non-polar.

The first stages of the circuit especially require quietness to function properly. Therefore, no LED is used to display the switching action of U1, although this might be helpful. Also, no LED is used to show the state of the output of either U4 or U5. Where an LED is indeed essential in the first stages (LED1), this uses a high value ballast resistor (R6). Therefore, an ultrabright or high efficiency LED is used in this position.

A special problem presents itself in the form of the power section (U7 and its surrounding components) and motor M1. This has already been described in brief.

Taking the example of U7a, when the output of U7a goes high, capacitor C12 is charged, and bilateral switch U6c conducts. This means that the potential at the junction of R11 and U6c goes high. Therefore, with trigger pin 6 being held high, this is disabled for a moment, giving the circuit time to settle after the motor has been energized.

LED2 and LED3 are included in the blanking described. As small as their power consumption is, these alone would be capable of significantly desta-

bilizing the circuit during switching.

Finally, a power MOSFET H-bridge is used to turn the motor either clockwise or counterclockwise in response to pulses from IC7 ouput pins 5 and 9. The specified MOSFETs will turn any small motor without the need for heat sinks, yet remain generously within their limits. D4 and C15 are included to suppress back-EMF.

Current consumption of The Tracker is less than 10 mA on standby, so that operation off a 12 volt 7 Ah battery is feasible, and would likely carry the circuit through a few days of continuous use in a store-front window before requiring a recharge.

Finally, it would be a fairly simple matter to add speech to The Tracker. As an example, an ISD1400-series single-chip record and playback device would provide a simple option if suitable trigger inputs were arranged. Since these devices have versatile addressing capability, various spoken messages could be incorporated in the circuit. Comprehensive data is available at **www.isd.com**

Electronic Construction

The Tracker is built on two PCBs, one each for the processing and sensing circuitry. Two further PCBs (an upper and a lower plate, consisting of three concentric circles of copper track) are required for the construction of the neck, which in the prototype has free 360° rotation. PCB patterns are available for download on the *SERVO* website (**www.servomagazine.com**). An early prototype used an umbilical cord between PCB 1 (the body) and PCB 2 (the head), which on one occasion led to complete self-strangulation! The upper plate makes contact with the lower plate through three sprung wires (or brushes) as shown in the photographs.

Note that U1, U2, U6, and U7 are CMOS devices, and require care when handling (first discharge your body to ground). Because PCB 1 is not small, I would recommend the use of dual-in-line pin (DIP) sockets throughout.

Starting with PCB 1, begin by soldering the solder pins, the seven DIP sockets, and 32 jumper wires. Then solder the resistors, the diodes, the potentiometers, the capacitors, and the power MOSFETs, finishing with the LEDs (these should have suitably long legs for mounting on the case — and note orientation). Use suitable lengths of connecting wire to connect S1 and the DC power socket (points F and G in Figure 3). The three solder pins near potentiometer VR1 are taken to the lower plate of the neck as shown, with suitable lengths of connecting wire.

Turning to PCB 2 (the smaller PCB), solder the resistors and capacitors, then add the LDRs — leaving long enough legs for these to be "splayed" (see below).

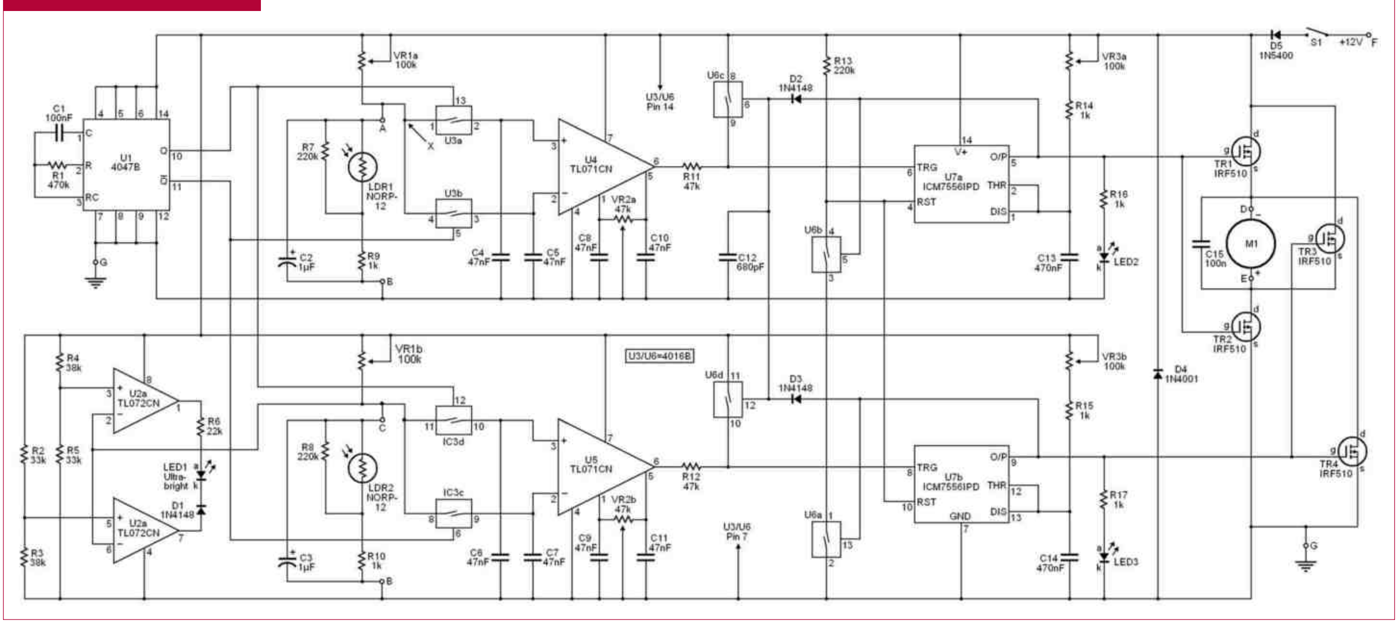
When an LDR is in its "naked" state, it has a very wide viewing angle, and its sensitivity is dull. The sensitivity may be greatly increased by making it "look" down the length of a narrow, black tube. In this case, three-inch long black tubes are recommended. For maximum range, try longer tubes — however, this reduces the field of vision, which can be self-defeating in some lighting situations. The tubes are later fixed to the head assembly, so that vibration is reduced to a minimum.

Once soldering is complete, insert the ICs in the DIP sockets, observing the correct orientation, and mount potentiometers VR1-VR3, LED1-LED3, and S1 and the DC power socket on the case.

Mechanical Construction

The motor is mounted firmly on the top of the case, with its "face" being flat horizontal. This is a 12 volt DC bidirectional motor with fairly low revs (650 RPM in the prototype), and good torque. The circuit allows for more than a little latitude when it comes to the motor's speed, so that various, similar DC motors may be tried.

.:. Figure 3 .:.



.:. Parts List .:.

Resistors	All 1/4W, 5% unless noted	**Semiconductors**	
R1	470 K	D1-D3	
R2, R5	33 K	1N4148	
R3, R4	39 K	D4	1N4001
R6	22 K	D5	1N5400 (or to suit motor)
R7, R8, R13	220 K	LED1-LED3	5 mm ultrabright red LED
R9, R10, R14-R17	1 K	TR1-TR4	IRF510 power MOSFET
R11, R12	47 K	U1	4047B CMOS oscillator
LDR1, LDR2	NORP-12	U2	TL072CN dual JFET op-amp
VR1, VR3	Dual gang 100 K linear pot	U3, U6	4016 CMOS quad bilateral switch
VR2	Dual gang 47 K linear pot	U4, U5	TL071 JFET op-amp
		U7	ICM7556IPD dual CMOS timer
Capacitors			
C1, C15	100 nF	**Miscellaneous**	
C2, C3	1 µF electrolytic 16 V	M1	12 volt DC gearhead motor
C4-C11	47 nF		(All Electronics CAT # DCM-208)
C12	680 pF	S1	On-off switch rated 1A
C13, C14	470 nF	PS1 (optional)	12 volts DC 1 amp power supply
C16-C21	100 µF electrolytic 16 V		<30 mV ripple
C22	1000 µF electrolytic 16 V	SK1	DC power socket to suit PS1

Wire up the bottom neck plate, mounting it on the face of the motor. Solder sprung wires (brushes) to the upper neck plate, and fix this on the motor's shaft, ensuring that all the brushes make good contact with the circular copper tracks on the bottom plate, and that the upper plate is flat parallel with the bottom plate. Wipe both plates with alcohol or methylated solvent before securing them, since residues from their manufacture might dirty the brushes.

Construct a central cylinder which will enable the upper plate to fit tightly onto the motor's shaft. I did this with soft copper plate which I wrapped tightly round the shaft, then soldered rigidly into place. The upper plate should then slide tightly on and off the motor's shaft. If this proves not to be sturdy enough, epoxy glue is suggested. A head is then built onto the upper plate. For this I used stiff card stock, and added some sparse "decoration" as seen in the photographs. The head construction also serves to support the eye-tubes.

The eye-tubes were splayed at 65° in the prototype. If this angle is reduced, The Tracker may lose you too easily as you walk past.

Set-up and Troubleshooting

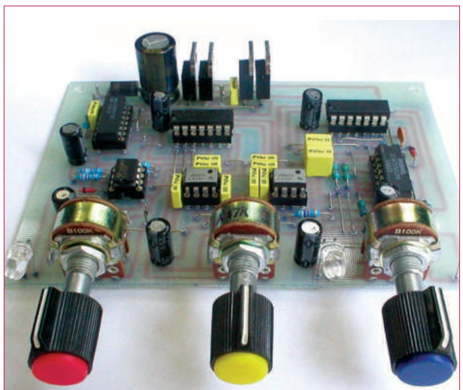
Turn back (counterclockwise) all three potentiometers, plug 12 volts DC into The Tracker's DC power socket (center pin positive), then switch on. If a 115 volt AC to 12 volt DC wall pack is used, this should be rated 1 amp with 30 mV RMS ripple or less, otherwise the circuit's sensitivity could be compromised. In other words, a high quality regulated wall pack is required.

At this point, The Tracker's head should not be moving, except perhaps for one or two twitches at switch-on. The circuit takes a minute or more to fully settle, and may exhibit unexpected behavior before this.

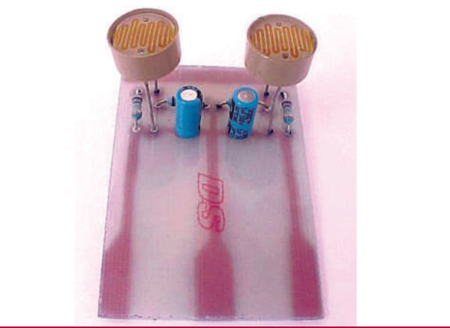
Turn up (clockwise) dual potentiometer VR1 until LED1 illuminates. If this does not illuminate, the light level might be out of range. Unless it is far out of range, this should not present a problem — simply turn the potentiometer to the brightest (clockwise) or dimmest (counterclockwise) light setting. LED1 might blink on and off during operation, depending on the light level perceived by the circuit at each turn of the neck.

Next, turn up (clockwise) dual potentiometer VR2 until LED2 and LED3 blink when there is motion before the eyes. If you turn this up too far, the AND logic described above will kick in and tend to cancel out the response of both eyes — or one or the other LED will blink randomly. If the head is properly connected, it will now twitch both clockwise and counterclockwise when it senses motion before the eyes.

We now require more decisive motion of the neck. For this purpose, dual potentiometer VR3 is turned up (clockwise) until the neck turns through a suitable arc to effectively track a person walking by. The setting of VR3 will vary according to the motor used, and the distance and speed of people walking by. The motor should turn the neck so that the eye which is triggered advances its position ahead of the motion it has detected (i.e., ahead of a person's path), while not advancing the other eye too far. Each time the neck turns, the head should more or less turn to face you directly. If the head



.:. Main processing PCB .:.

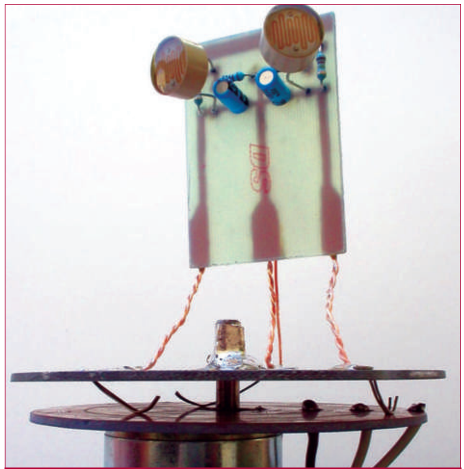

.:. Sensor PCB .:.

turns the wrong way, simply reverse the leads of the motor.

If the circuit does not work as described, switch off and carefully re-check. Ensure that there are no solder bridges on the PCB, that all components are inserted correctly, and that all inter-wiring is correct.

Simple trouble-shooting of the circuit may be done with an LED and a 1K series resistor, with the LED's cathode being wired to ground. Touch the resistor to pin 10, then to pin 11 of U1. The LED should flash both times. Touch it to U4 pin 6, then to U5 pin 6. With the correct setting of VR2, the LED should blink both times when a hand is moved in front of the corresponding eye. All being well at this stage, any further problems will lie in U6, U7, or the power MOSFETs. U2 is incidental to the circuit, and is unlikely to cause any problems. A further problem might lie in interference between the two eyes. If a hand is moved in front of one eye and the LED of the opposite eye flashes also, then there is interference.

Assuming that the circuit has been given ample time to settle, try turning back VR2. If this leads to poor sensitivity, a poor quality power supply would be the No.1 suspect. The perfect solution in this case would be a 12V battery. Interference from the motor or physical vibration of the head should be the next suspects. The solution in this case would lie in a longer blanking period, by increasing the value of C12. I myself needed to add 470 pF in parallel with C12 after I added a head to the "head scaffold," due to increased vibration and momentum with the added weight. Make sure that all parts of the head are well secured. Another potential problem would be particularly bad lighting conditions (i.e., sodium lamps). In this case, "easier" lighting would be recommended, although an increase to the values of C2 and C3 might help. The Tracker will work best in situations of good contrast (i.e., shadows on a white wall). If a room has large, dark areas on the one hand, or especially bright areas on the other (such as wall lamps) The Tracker might become confused — due partly to the fact that it sees "in monochrome" and dark or light patches might obscure shadows. Uniform brightness in a room will work best. If The Tracker is to be used in bright daylight or sunlight, the values of VR1 and R7-R10 should be adjusted to give a potential of about half the supply voltage at point X.


.:. Head scaffold with neck plates and sprung wires .:.

With some experimentation, The Tracker may be set to transition seamlessly from natural to AC lighting — but this, unfortunately, will not occur at maximum sensitivity for both. If maximum sensitivity under natural lighting triggers the circuit under AC, then adjust for maximum sensitivity under AC — and vice versa.

The author may be contacted at **scarboro@iafrica.com**

Welcome to Robytes, *SERVO's* collection of random bits of robot news from around the world. Every issue you'll get a good cross section of what's going on. Got a good story on robots? Email me: **news@robotics-society.org**

And, if you'd like to get even more robot news delivered to your in-box (no spam, just robo-news), drop a line: **subscribe@robotics-society.org**

— David Calkins

Smart Dust Millirobots Take a Walk

While most robotic engineers are working on making bigger robots, UC Berkeley professor Kristofer Pister has been following the idea that smaller is better. Using circuit designing techniques, he's building robots that will soon be invisible to the naked eye. They use microelectromechanical systems (MEMS), which act like an inchworm to give the bots better crawling capabilities. While these robots aren't quite capable of outrunning Carl Lewis, they have proven their abilities to scamper about. Talk about wanting to be a fly on the wall — Pister's microbots may finally be able to let you know what your co-workers *really* think about you.

http://robotics-society.org/servo/001

Robot Tries to Put Sniffer Dogs Out of Work

Pity the poor sniffer dog. First someone shoves a dirty shirt under his nose, and then he drags some guy through the woods looking for the bad guys. Andy Russell of Monash University in Australia hopes to put the sniffer dogs out of work. He's developed robots that can detect a scent and follow it to its source. Although not yet as "scents-itive" as dogs, the bots will eventually be able to precisely recognize individual odors and alert humans to their source and exact composition — not just "it's a bomb," but such details as the exact type of explosive used. The bots should have no problem finding my laundry pile ...

http://robotics-society.org/servo/002

Robots Try to Put David Beckham Out of Work

Pity poor Posh Spice — currently married to one of the greatest soccer players ever. FIRA — the Federation of International Robot Soccer Association — held its annual competition in Vienna at the beginning of October. Robots, both walking and on wheels, are quickly catching up to us mere mortals. The goal of FIRA is to have a bipedal robot team beat a human team by 2050. T

he recent games consisted of both wheeled and bipedal bots — the goal of the wheeled bots being to accurately find the ball, opponents, and goal — while the bipeds focus on being able to stand and kick. Soon, the two types will converge to create autonomous bipedal robots that can independently find the ball, determine friend from foe, kick the ball into the opposing goal, and just about anything else Messr Beckham can do. Victoria will need to invest in batteries ...

http://robotics-society.org/servo/003

Snake Robots Slither Into the Future

Tokyo researches have developed new snake robots to help find survivors trapped in collapsed buildings after earthquakes, explosions, and bombings. Fumitoshi Matsuno of Tokyo's University of Electro-Communications' Mechanical Engineering and Intelligent Systems, has spearheaded the project which developed snake-bots that "can go into narrow places and their long and thin bodies can disperse the weight to prevent a secondary collapse of wrecked structures," something that traditional wheeled bots can't do. These robots will really advance the science, but they could have saved

themselves a lot of time if they'd called Gavin Miller first.
http://robotics-society.org/servo/004

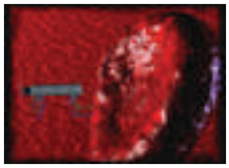
Korean Industry Works to Develop Service Robots

Home robots have long escaped our dreams of an in-house service bot that will do our laundry, dishes, and take the dog for a walk. But the International Federation of Robotics is hoping that in-home service robots will soon be as prevalent as cars — growing from a $400 million dollar industry in 2003 to a $2.2 billion dollar industry by 2005 — and as much as $70 billion by 2010. The Koreans, hoping to capitalize on the explosive growth, are focusing their energy on creating everything from vacuum bots to cleaning bots. With heavy hitters such as Samsung and Hyundai leading the way, better bots are within our generation. I just hope that my future butler bot has as cool a voice as B-9 did in "Lost in Space."
http://robotics-society.org/servo/005

New Walking Robots for Under $100.00

Mark Tilden, the famous inventor of BEAM robotics and annoyer of generals everywhere, is coming out with walking robots which will give ASIMO a "run" for its money. Spurned by the success of BIO bugs, and on loan from NASA (until they stop crashing his robots into mars), he's introducing a new robot — the "RoboSapien" — a full function, fast moving robot minion suitable for all your world domination needs. It features real multi-speed fast dynamic walking, running, and turning, 67 pre-programmed functions including pick-up, throw, kick, sweep, dance, fart, belch, rap, and half-a-dozen different kung-fu moves. And it even speaks fluent international "caveman." All this without a computer. The big question, of course, is will it take my Aibo for a walk, or try to steal its lunch money.
http://robotics-society.org/servo/006

Nanorobots to Swim Through the Bloodstream



As a boy, I remember watching the old movie "Fantastic Voyage" (later remade as "Innerspace") about a miniaturized submarine that cruises through a man's body in order to perform microscopic surgery, and thinking "No way could they do that! Cool movie though." I've learned a lot in my old age. One thing is never to say "No way they could do that."

Well, Rutgers University is building robots that someday will travel your bloodstream to repair damaged cells, tissues, and DNA.

A prototype of their Nano Motor is expected to be unveiled in 2007, with research and development funded by a four-year $1,050,017.00 grant from the National Science Foundation and its Nanoscale Science and Engineering program.

These motors — 1/50,000th the width of a human hair — will truly revolutionize how we look at medicine and the body. So long as you don't sneeze them out ...
http://robotics-society.org/servo/007

To the Moon, Alice!

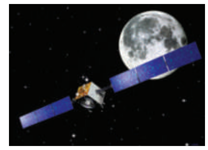


Photo courtesy of ESA

The European Space agency launched its first lunar robot probe Sept. 28th from French Guiana (erm, robots, space missions, and French Guiana? Where do I apply?) The probe, SMART-1 (Small Missions for Advanced Research in Technology), is the first of ESA's Small Missions for Advanced Research in Technology. Carrying several miniaturized instruments, it's en route to the moon using solar-electric propulsion and a spiffy new ion engine. These incredible ion engines work similarly to rockets, but they fire out a propellant gas much faster than the jet of a chemical rocket — delivering about 10 times as much thrust per kilo of propellant. Electric guns fire out charged atoms, which is what gives the engine its "ion" name. SMART-1 will make the first comprehensive inventory of key chemical elements on the lunar surface, and investigate the theory that the Moon was formed following the violent collision of a smaller planet with Earth. It will also search for ice — something everyone hopes to find on the moon, as it is the key to colonizing the moon. I guess Norton will have to start packing.
http://robotics-society.org/servo/008

EVENTS CALENDAR

courtesy of ROBOTS.NET

November is a busy month for robot competitors — with the 24th annual All Japan MicroMouse Contest being the biggest event of the lot. There are also contests being held by several of the major robot clubs in the US including CIRC and ChiBots in Illinois, and the DPRG in Texas. And once again, Texas A & M University will be hosting the annual state championship for the BEST competition.

The first quarter of a new year is usually a bit slow but there are some notable exceptions this year with the APEC MicroMouse Contest scheduled for February in CA and the much anticipated DARPA Grand Challenge coming in March. With a one million dollar prize, the DARPA event is shaping up to be one of the highest profile events ever for autonomous mobile robots.

— R. Steven Rainwater

November 2003

8 **CIRC Autonomous Sumo Robot Competition**
Peoria, IL — This Central Illinois Robotics Club event will include an R/C robotic combat event in addition to autonomous sumo.
www.circ.mtco.com/competitions/2003/sumorules.htm

8-9 **Olimpiada Robotica**
Commercial Center Vizcaya de Medellin, Columbia — An annual maze-running contest.
www.upb.edu.co/automatica/olimpiada/olimpiada.html

9 **ChiBots Robotics Contest**
Schaumburg Public Library, Schaumburg, IL — Events include basic and advanced line following, solaroller, and the amazing "Pound of Wood Mini-Sumo Challenge."
www.chibots.org

15 **DPRG Table-Top Robot Contest and Talent Show**
Dallas, TX — The last DPRG Talent Show was in 1999 — they don't happen often enough to miss!
www.dprg.org/competitions

22 **PAReX Autonomous Robotics Competition**
Challenger Learning Center, Phoenix, AZ — Autonomous Mini Sumo and Maze Solving. Mr. Ball is lost in the land of snakes and scorpions. Can your robot find him in time?
www.parex.org/autoevent1.shtml

20-22 **Texas BEST Competition**
Texas A & M University, College Station, TX — If your school doesn't have a team, check the web site to find out how to get one started.
www.texasbest.org or **www.bestinc.org**

21-23 **All Japan MicroMouse Contest**
The Panasonic Center, Tokyo, Japan — This is the 24th annual contest; 24 years of optimization have produced robots that can solve these mazes in 10 seconds instead of the original 10 minutes.
www.bekkoame.ne.jp/~ntf/mouse/taikai/taikai.html

December 2003

6 **Boonshoft Museum LEGO Mindstorms Robotics Competition**
Boonshoft Museum, Dayton, OH — Local competition for the FIRST LEGO League. Winners move on to the state competition.
www.boonshoftmuseum.org/special_events.php3

6 **Penn State Abington Robo-Hoops**
Penn State Abington, Abington, PA — Yes, this is autonomous robot basketball. Each robot has 60 seconds to make up to four baskets by shooting or dunking.
www.ecsel.psu.edu/~avanzato/robots/robohoops.htm

13 **LEGO MY EGG-O Robotic Egg Hunt**
Great Lakes Science Center, Cleveland, OH — Bi-annual student contest of the Case Western Reserve University Autonomous LEGO Robotics Course.
http://www.eecs.cwru.edu/courses/lego375/

15-16 **Eastern Canadian Robot Games**
Ontario Science Centre, Ontario Canada — In addition to the expected BEAM events, there's also a regional for the Trinity Fire-Fighting contests and autonomous sumo.
www.robotgames.ca

January 2004

24-26 **Yantriki TECHFEST 2004, IIT**
Bombay, India — This is a huge technical festival

involving over 15,000 students from 750 colleges across India. There are a lot of other technical contests in addition to the robotics events.
www.me.iitb.ernet.in/yantriki or **www.techfest.org**

February 2004

22-26 **APEC MicroMouse Contest**
The Disneyland Hotel, Anaheim, CA — If you can't catch the Japanese MicroMouse event, this one should be just as interesting with some very advanced robots.
www.apecconf.org/2004/APEC04_Home_Page.html

March 2004

13 **DARPA Grand Challenge**
Los Angeles, CA — The autonomous LA to Vegas cross-country, off-road, race for a one million dollar prize. Not your average robot contest.
www.darpa.mil/grandchallenge

28 **University of Florida Student Robotic Competition**
Univ. of FL Conference Center, Gainesville, FL — This is the only robot contest you'll see where the robots are required to obey Asimov's three laws as part of the rules!
plaza.ufl.edu/niezreck/Robots_Competition_2004.html

Robotics Showcase

Robotics Resources:

Lighting Effects

So, you have this great robot that can follow a black line around the room. You and I know this is a terrific accomplishment, but it's lost on the non-practitioners of the robotic art. They respond to robots on a far more shallow level — like how much damage it can inflict, or if it's "cute" like R2-D2. Few onlookers will ever ask you "what does it do" if your robot makes funny sounds or blinks lots of lights.

While not a construction material, and certainly not necessary to make your robot smart, lighting elements add style and decoration to your robot. The right lights can make even the most boring line follower look cool. Lighting can also be used for practical applications. For instance, electroluminescent wire could be attached to the floor and used to prevent a robot from wandering outside its perimeter. Or high brightness flashing LEDs could be used in multiple-player robot soccer. Ultraviolet lamps (and ultraviolet detectors, typically used for testing of paper money) could provide an optical proximity system based on the fluorescence of materials.

In this column, we'll examine several popular types of lighting you can add to your robot. All are fairly inexpensive and can be purchased locally or through the Internet.

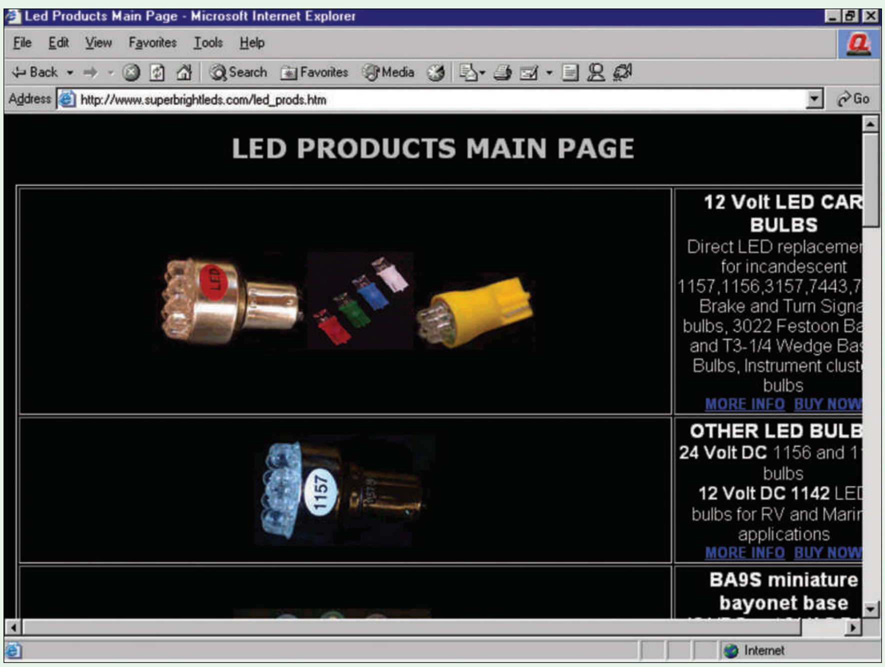
Super Bright and Specialty LEDs

Light emitting diodes (LEDs) have been around for decades, but a fairly recent innovation is the super bright LED. These put out a bright beam that can be seen for hundreds, if not thousands, of feet. They're available in just about every color of the rainbow, including blue and even white.

Visible light LEDs are classified by their light output, rated in candles (also called candela). Until recently, few LEDs produced more than one candle, so the typical specification was in millicandles (mcd) — or thousandths of a candle. A 100 mcd LED produces 100 millicandles — or 1/10 of a candle. Super bright LEDs, on the other hand, produce several candles of light. These may be rated in candles or millicandles. For instance, a 4,500 mcd LED produces 4.5 candles — that's bright! And some are even brighter.

Color is obviously one feature to look for when shopping for super bright LEDs. You'll also want to compare the beam spread. The highest outputs are achieved by using a narrow 10 or 15 percent beam, rather than the more typical 30 percent. For the latter, the LED may produce the same amount of light, but disperse it over a wider area. As a result, the measured point intensity is lower. The brightest of the super bright LEDs are so bright they are painful to directly look at. So don't! In fact, they can cause the same sort of blind spots as any high intensity light.

This is especially true of ultraviolet LEDs, which produce light at 400 nanometers, just below the visible spectrum. UV LEDs are typically used with fluorescent inks and dyes. On mobile robots, limit their use to "undercarriage" lights to avoid the beam from pointing directly into anyone's eyes. UV light is more interesting for what it does to fluorescing materials, than as a direct light source.



Find most any color LED at **SuperBrightLeds.com**

For Robotics

Cold Cathode Fluorescent Tubes

Cold cathode fluorescent lamp (CCFL) tubes are commonly used to "hop-up" personal computers with glow effects. The light consists of the tube itself, plus a high voltage inverter. Inside the tube is a coating that causes it to glow in any of several striking colors, as well as white and ultraviolet. (Be careful of the ultraviolet tubes unless you know it's safe — short wave ultraviolet can cause sunburn and blindness.) The inverter steps up the 5 to 12 volt battery voltage to 100 or more volts, to light the tube.

CCFL tubes are available in different lengths. For robotics applications, the shorter 100 mm (about four inches) length is about right. Another common length is 300 mm (about 12 inches). If the tube is "bare," you'll want to place it in a clear, rigid protective tube. You can purchase these at some home improvement stores, as well as specialty plastics outlets. The tube helps prevent breakage and the possibility of small shards of glass flying everywhere. If a rigid tube is not practical, clear flexible hosing, available at any pet shop that sells aquarium supplies, is the next best choice. The tube may still break if something strikes it, but the glass will remain inside the hose.

Use caution when handling the tube and inverter. Though the current produced by an inverter is low, the shock is unpleasant, and it may cause you to recoil and drop the tube.

Electroluminescent Panels

Electroluminescent (EL) panels are used in products ranging from nightlights to LCD backlights. The typical color is a soft green, but other colors are possible, including reds, oranges, and blues. Overlay filters can be used to alter the color, but the choices are limited. Electroluminescent panels require a high voltage (90 volts or higher), and like the CCFL products, this is accomplished with an inverter. The inverter steps up the battery voltage to 90-120 VAC.

You can purchase EL panels as surplus, and experiment with them. Look for panels with solid leads already attached; you can solder wires to the leads. Less useful are panels that require a pressure connection to make electrical contact. These are harder to solder to.

The chaser panel kits sold by All Electronics offer a great way to dip your toes into the exciting world of electroluminescent panels. The kit includes an inverter, color filters, and a 3.75-inch by 1.7-inch EL strip that provides multiple connection points. The strip can be cut into smaller pieces. The inverter can power up to five separate strips, and provides 32 pre-programmed lighting sequences.

Electroluminescent Wire

Imagine a flexible neon sign — that's what EL wire is. EL wire looks a lot like small plastic tubing, but when electricity is applied, it glows in a rainbow of colors. Here's how it works: At the center is a solid copper conductor. This conductor is coated with an electroluminescent phosphor. To excite the phosphor, two very fine wires are wrapped around the center conductor. Covering this whole arrangement is a clear plastic sheath, which also protects everything inside.

Apply current to the wires and the phosphor lights up. Different colors are produced by varying the chemical makeup of the phosphor, altering the tinting of the plastic protective sheath, varying the voltage, and/or varying the frequency of the current driving the wire. The end result is a brightly colored glowing wire. EL wire has several uses in robotics. Here are just some of them:

- First and foremost, it looks cool! Wrap some EL wire of different colors around the periphery of your robot to give it some pizzazz.
- Small strips of EL wire, of a certain color, can be used to identify robots in a competition. If the robots are equipped with filtered light sensors, they can even differentiate friend from foe on the battlefield.
- EL wire can provide illumination for the robot for use in object detection. When used in conjunction with cadmium sulfide (CdS) cells, the reflected glow of the EL wire can be detected and used for proximity sensing. (In addition, many red colored phosphors will emit a certain amount of near-infrared light, which is detectable with ordinary infrared photo-transistors.)
- A strip of EL wire on the floor can be used for a line tracking robot. On the underside of the robot, affix sensors to detect the glow of the wire.
- Strips of EL wire can be placed around the periphery of

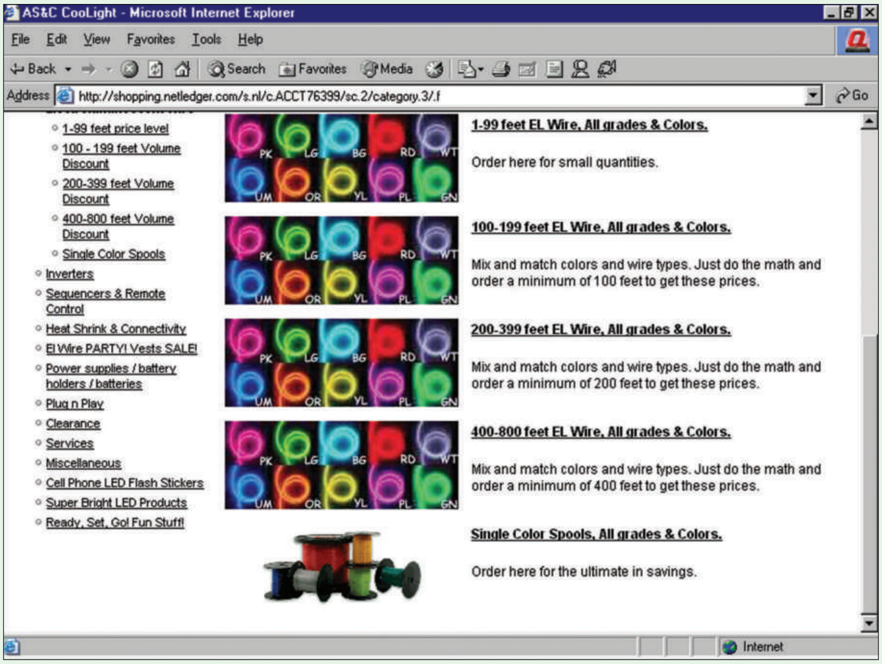
by Gordon McComb

a room or along the floor, to serve as a kind of electronic fence. Sensors on the underside of the robot detect the light from the EL wire. A bonus: unlike a painted line, the EL wire can be switched on and off, thereby allowing the robot to exit the fenced area, should that be necessary.

EL wire is driven by a high voltage alternating current. But it need not be plugged into a wall outlet. Rather, the wire uses small, self-contained inverters that produce the required voltage from a small DC source (usually 3 to 12 volts; AA batteries are sufficient).

Inverters are not terribly expensive — consumer models retail for $7.00 to $12.00. You'll have good results if you add more inverters to drive additional strands of EL wire, rather than try to do it all from one unit. Additionally, you can opt for an inverter that blinks the EL wire at specific intervals, or keeps it on continuously. Specialty inverters are available with built-in sequencers that, in turn, selectively activate several strands of EL wire. Note that inverters are available at different operating frequencies — from 400 Hz to over 12,000 Hz. The brightest outputs are provided at the higher frequencies. The color of some phosphors can be altered by changing the frequency of the AC excitation. For example, the "blue" phosphors can be changed from green to blue by varying the frequency between 400 and about 6,000 Hz.

Color choice varies by manufacturer, but most offer the following, in diameters from 1.3 millimeters (called "angle hair") to 5.0 millimeters: aqua (blue/green), deep red, green, indigo (deep blue), lime green, orange, pink, purple, red, white, and yellow. The blues and greens tend to be the most vibrant colors.



Coolight.com offers electroluminescent wire in a variety of colors and thicknesses.

Body Jewelry

Light-up body jewelry uses various types of LEDs — flashing and continuous — electroluminescent panels and wires, and even Cyalume glowsticks. Glow-in-the-dark sticks can be purchased at mall stores and even discount retailers such as Wal-Mart. Look for a party shop, such as Spencer Gifts (mail order and mall stores), for light-up body jewelry. For more online choices, try various **Google.com** searches:

- glowstick
- rave lights
- glow jewelry
- magnetic LED earrings

Of particular interest are the LED earrings. Most use a magnetic backing rather than a piercing or clip. They're battery powered and pulse in any of several colors. Colors vary — typical are alternating blue and red. You can attach the earrings to your robot using glue, double-sided foam tape, or even with a flexible magnet strip.

Lasers

Lasers can be used for unusual and brilliant lighting effects, as long as your robot will be used in a protected environment, without curious kids who might pick it up and look into the laser light. Laser pointers are battery powered, and relatively inexpensive (many sell for under $10.00). The most common color is red, but laser pointers in green and a few other colors are available. Cost is considerably more for the latter, as non-red laser diodes are more expensive to manufacture.

You may opt to use the laser pointer as-is, mounting it directly to the robot. The on/off switch is spring-loaded, so you'll need to work out a way to keep it depressed. Or, you can remove the laser diode from the body of the pointer, and activate it via a transistor or relay. Removing the laser diode is not always as easy as it sounds, or even recommended — the metal barrel of the pointer acts as a heat sink. Without the heat sink, the laser diode may prematurely burn-out. You will also need to provide regulated voltage. A limiting resistor may be needed to prevent the laser diode from pulling too much current from the robot's power supply.

Of course, the usual precautions of using lasers should be observed. Avoid looking directly into the beam, and don't allow the robot to be used in any situation where the beam can accidentally point toward anyone — or any animal, for that matter.

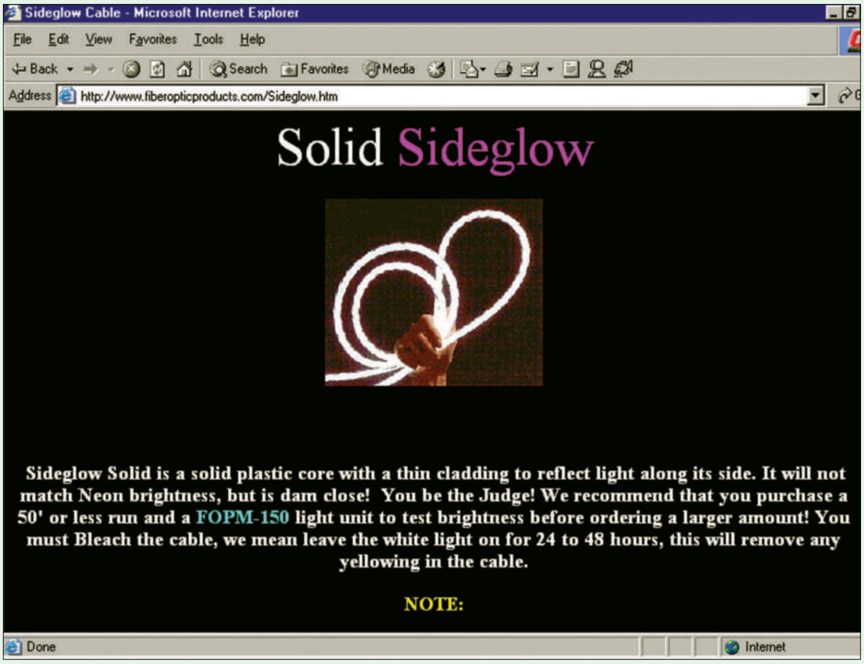
One idea for a laser-equipped robot is "light writing" using the open bulb setting of a 35mm film camera. Set the camera on a tripod, set the camera to "bulb" (the shutter stays open until you release it), turn off the lights, and let your robot loose. The laser will "paint" streaks of colored light on the film as it roams around the room. S

SOURCES AND SIDEBARS

Christmas Decorations

Christmas is one of the best times to find unique lighting systems for your robot. An increasing number of products are designed to run off low-voltage DC, so they're suitable for battery-operated robots. Examples I've seen recently: mistletoe that lights up when someone stands under it, a glowing Santa that speaks when someone approaches the front door, and chaser-light tree ornaments operated by two AA batteries.

Wait until after December 25th to get the good deals. Stores routinely offer unsold Christmas decorations at 50% off, or more. Same goes for the days right after Halloween. Though most Halloween lighting is in oranges and reds, they're a cheap source of LEDs, incandescent lights (strip off the colored gel filters), and glowsticks.



Fiber Optic Products offers side glow fiber optic cable, similar in functionality to electroluminescent wire.

Fiber Optics

Fiber optics is an old technology, and it's easy to forget when planning light effects for your robot. But there's still plenty of life left in good ol' fiber optic lighting, and new technologies make it even more exciting. Case in point: so-called "side glow" fibers emit light over the length of the strand, not just the end. They look more like electroluminescent wire, but can be made to glow any color, even alternate colors.

Surprisingly, fiber optic strands suitable for lighting effects can be hard to find. Most fiber optics sold these days are for data transmission — expensive. Rather, you want cheap fiber optic strands used to make "fountain lamps" popular in the early 1970s. Fortunately, a few retailers such as Target and Spencer Gifts sell low-cost reproductions of these lamps. You can yank off the fiber and use it in your robot projects. If you need longer lengths or a particular style or type of fiber, check out Fiber Optic Products, listed in the Sources section. They offer end glow and side glow fibers, lamps, bundles, fluorescent fiber optics, and associated products.

Sources

All Electronics

www.allelectronics.com

All Electronics (local stores in Los Angeles, CA, catalog mail order elsewhere) offers high brightness LEDs, electroluminescent panel kits (cut out shapes to make your own), CCFL lights, and high voltage inverters.

AS&C CooLight

www.coolight.com

Electroluminescent wire, inverters, and sequencers. Products can be purchased through their web page.

About the Author

Gordon McComb is the author of the best-selling *Robot Builder's Bonanza* and the *Robot Builder's Sourcebook*, both from Tab/McGraw-Hill. In addition to writing books, he operates a small manufacturing company dedicated to low-cost amateur robotics, **www.budgetrobotics.com** He can also be reached at robots@robotoid.com

Black Feather Electronics
www.blkfeather.com

A cornucopia of unique electronics items: connectors and cords, audio, gadgets, laser pointers, mini-cams, soldering, parts and switches, power, test equipment, kits, tools, video; high-brightness LEDs, and electroluminescent wire.

Cool Neon/Funhouse Productions
www.coolneon.com

Cool Neon sells electroluminescent (EL) wire — a wire that glows when subjected to high frequency supply voltages. Select colors and thicknesses, add a driver/inverter, and you're all set to go. Website includes some details on soldering EL wire.

Don Klipstein's LED and Laser Information
http://misty.com/people/don

Everything you ever wanted to know about lamps, LEDs, lasers, and strobe lights.

ELAM Electroluminescent Industries, Ltd.
www.elamusainc.com

ELAM is the manufacturer of many of the electroluminescent wires sold under varying trade names (such as Neon Rim, Cool Wire, Live Wire, and Cool Neon). ELAM's name for the stuff is LyTec. The company provides technical details and specification sheets on the wire and inverter/driver products.

Fiber Optic Products
www.fiberopticproducts.com

Fiber optics for lighting effects. Includes the traditional “end glow” fibers, where light goes in one end, and comes out the other, as well as “side glow” fibers, where light is emitted through the shaft.

Gilway Technical Lamp
www.gilway.com

LEDs and lamps. Specialty products include superbright LEDs in all colors — from ultraviolet to infrared.

Glowire
www.glowire.com

Glowire sells electroluminescent wire in different thicknesses and colors, as well as the necessary DC inverters used to drive the wire. They also provide "laser LEDs," which are really very bright colored LEDs. Useful if your robot needs bright headlights.

J. A. LeClaire
www.neontrim.com

Sellers of Neon Trim electroluminescent wire, inverters, and programmable sequencers.

Olmec Advanced Materials, Ltd.
www.olmec.co.uk

Resellers and fabricators of specialty materials, including Surelight electroluminescent wire.

RepairFAQ: Sam's Laser FAQ
www.repairfaq.org/sam/lasersam.htm

From Sam Goldwasser's RepairFAQ: Using and abusing (how not to) lasers. Includes a good section on safety.

Spencer Gifts, Inc.
www.spencergifts.com

Spencer Gifts is a retailer of the unusual, including gag cards, joke gifts, adult novelties, and unusual lighting effects (such as UV, fiber optics, and electroluminescent). You can order online, or visit a store near you. Most Spencer Gift stores are in fashion shopping malls.

Super Bright LEDs
www.superbrightleds.com

Super Bright LEDs offers a wide assortment of high brightness LEDs in a multitude of colors. Datasheets are provided for all products. They also sell LED lamp products such as car running lights and “glow tubes.” Many of these are applicable as attention-getters on robots, as well.

Surelight
www.surelight.com

Surelight sells electroluminescent (EL) wire in various colors and thicknesses, as well as EL drivers, light sticks, and other specialty lighting goods.

That's Cool Wire/Solution Industries
www.thatscoolwire.com

That's Cool Wire sells electroluminescent wire and driver modules.

Xenoline
www.xenoline.com

Xenoline sells electroluminescent and high-tech “glow-in-the-dark” products. This stuff is useful to “dress up” an otherwise boring robot, to provide a guide path or fence, or to provide illumination of a specific color for a robot with vision. Key products include:

- Xenopaks — Kits of different colored electroluminescent wire and driver circuits
- ZLine — Flat electroluminescent light strips (several colors in the orange to blue spectrum), 1/4” wide x 28” long
- Gamma Rays — Ultra-bright colored (blue, red, green, yellow, and white) LEDs intended as a light source
- Krill Lamps — Compact self-contained electroluminescent “lanterns” in a variety of colors
- Laser pointers — Hack ’em to make any pinpoint light source for your robot

NEURONS FOR ROBOTS

by Harold Reed
edited by Chris Hannold

These days, robot builders are fortunate in that there is a host of inexpensive and easily adaptable mobile robot base platforms available, and there are even more choices when it comes to control electronics. Everyone has his or her favorite platform.

However, the choices are severely limited when it comes to designing the actual programs that listen to sensors, control movements, and make decisions. A platform-independent method for designing control code would make it much easier for robot builders to share and expand upon previous work. That is what I hope to offer here.

We are interested not in how things look, but in how things work. The most interesting structures we see are living things. We want to build life like machines, and would like to know how they work. To do that, we need to understand sensors, brains, and motors, since every animal seems to have these. Also, we need to learn about neurons, functions, trees, and nodes, as well as apply some algebra and computer science to the system. Building anything requires that you have a tool set that is appropriate to what you are working on. After we look at neurons, we will construct a toolset to define them.

Table 1

Fact 1: **A brain is always between sensors and motors.**
Fact 2: **Brains are of different sizes.**
Fact 3: **Brains are constructed of neurons.**
Fact 4: **Neurons have synapses and a single axon.**

Let's start with some brain facts that are generally known. For example, we know that sensors, a brain, and motors are attached to a body. There are many sensors, one brain, and many motors. All living things, including microbes and cells, have some variety of this architecture. There is also a data flow which requires "writers" and "readers." Data always flows from writer to reader:

Nature >> Sensor >> Brain >> Motor >> Nature

This shows the data flow and position of each of the elements of any robot or living being. It can also be visualized as a circle with feedback through nature. Sensors read nature, and a brain reads sensors. Motors read the brain and act on nature, which changes what the sensors read. In living things, feedback is everywhere — from bottom to top.

Table 1 lists some common, obvious brain facts or *axioms.* From these facts, we can deduce a purpose:

Brains mediate between sensors and a motor.

They are sort of impedance matchers or transformers converting multiple inputs to separate outputs. A brain is the total assemblage of neurons and includes sensor and motor neurons.

Table 2

Neuron[j] = f(synapses[j]) **; from fact 4**
Brain = {Neuron[1]...Neuron[n]} **; from fact 3**

There is no universal form for this except as a list of transfer functions.

If a brain is the code, then neurons are the hardware. Designing brains requires writing code. Building brains requires assembling neurons that match the functions in the code. An example is given in Table 2.

From Fact 2, we can deduce that there must be a "least order" brain. Suppose there is no neuron. What does this mean?

Nature >> Sensor >> Motor >> Nature

This is the resulting data flow. Note that sensor and motor are singular here. From this we deduce that a brain is needed when sensors are greater in number than the number of motors.

A neuron is needed for mapping multiple inputs to an output. Since a neuron is a function, we can write an equivalent function on paper and build it in hardware. If we can make a neuron, we can make a brain.

We need some tools to write brain code. I call my tool set "Hal Algebra." In life, neurons form upside-down trees with many inputs leading to an output. In Hal Algebra, we'll call these *HalTrees* and we'll call neurons nodes. There are several types of nodes.

I use long variable names and try to flow the math into the language. If I have a variable name that is plural, then that means there is more than

Table 3

Operator	HalNode	Notation	Description
Tree nodes		*SNodes*	
-	CNode	O <= I - R	O is the difference of I,R
+	PNode	O <= I + R	O is the sum of I,R
o	ONode	O <= I o R	O is the Max(I,R)
a	ANode	O <= I a R	O is the Min(I,R)
>	GTNode	O <= I > R	O is I if I > R else 0
<	LTNode	O <= I < R	O is I if I < R else 0
is	ISNode	O <= I is R	O is I if I = R else 0
Single nodes		*TNodes*	
i	INode	O <= I(I)-R	O is integral of I
d	DNode	O <= d(I)	O is derivative of I
f	FNode	O <= f(I)	O is frequency of I
n	NNode	O <= n(I)	O is 0 - I
b	BNode	O <= b(I)	integer -> offset binary
Not	NotNode	O <= I)	If I = 0, O = 1 else O = 0
Switches		*SNodes*	
g	GNode	O <= I g R	O is R if I > 0 else 0
l	LNode	O <= I l R	O is R if I < 0 else 0
z	ZNode	O <= I z R	O is R if I = 0 else 0

one item attached. The math is based on simple algebra and the operations + (Add), - (Subtract), * (Multiply) and / (Divide). Ultimately, we will turn equations into machines. Equations have a single output, and one or more inputs separated by operators. A = B + C is a general example. A is the output of B + C, where B and C are inputs and + is the operator.

Z = f(X,Y) says that for every value of X and Y there is a value for Z, based on the function f. Z is the output, and X and Y are inputs. Functions will also become machines.

So far, I have made these functions, or nodes, shown as a table. "I" stands for Input, "R" is a second input, and "O" stands for Output. *SNodes* can be tree nodes and switches (IF-Then-Else for you code hounds). *TNodes* are single nodes that perform a complex function. Refer to Table 3 for a list.

Table 4 lists some similarities of neurons and HalTrees. There are also differences, of course. In the table, N is any counting number, c is node cycle time, L is column level, and S is the number of inputs.

There are some differences, mostly in favor of HalTrees:

1. HalNode headers connect tightly to data cable plugs. Neurons axons and synapses connect loosely and wetly. Global acting, hormonal-like actions are explicit in the brain code, that is, they must be programmed in.

2. The insides of neurons cannot be accessed. HalTrees can be accessed at any and every node.

3. Neurons can change their internal code based on input information. The designer of HalTrees must change code by rearranging connections based on experience. Headers make this possible in hardware.

The property of trees that allows us to measure *size* is the number of inputs the tree has. To make a larger tree, combine it with or add it to another tree. To make a smaller tree, take away some of the tree. Trees obey the rules of arithmetic:

Tree A = Tree B + Tree C

If you have a tree with B inputs and you add a tree with C inputs the result will be a tree with B + C inputs.This means that on your robot, you can start at a motor and build the neuron tree at will, expanding as you go. You can start with a two-input tree and end with a hundred-input tree by adding one node at a time. To add a node, open up a header and plug in another node or tree.

The only software you need to change is the brain's neuron list. There are many possible tree architectures, as you might have guessed. Here, we will ignore size and instead look at the shape. Here are a few examples using a Cnode at the motor (O is the difference of I,R). By now you should be visualizing data pouring into the inputs, and streaming out of the output in the examples:

• Command trees collect do's and don'ts for a motor:
Doing = Do - Don't

• Information trees collect direction for a motor:
Direction = Left - Right

• Collection trees gather information from sensors:
Touched = touchedLeft - TouchedRight

• Property trees collect object properties:
animal = living + being ; 2 = 1 + 1
man = rational + animal ; 3 = 1 + 2
rational = man - animal ; 1 = 3 - 2

Table 4

Property	In a neuron	In a HalTree
Data flow	Synapses >> axon	Inputs >> output
Input size	1 to N	1 to N
Data size	>= 2 bits	>= 2 bits (8 bits now)
Cycle time	t=(S-1)*c	t=(S-1)*c
Fan out	SL-1	SL-1
Functions	varied	See Table 3

Of course, there is more to this — several books more, but like everything, it starts simply. Your brain can grow as the complexity of your robot grows. Since code must be easily modified, I would also make the hardware easy to modify by providing easy connections with headers and sockets.

We can make nodes of sensors and motors. Let I, R, and O be headers on the nodes.

Carry the data flow on cables with plugs that plug into the headers, and you have the machinery of the data flow captured. Nature plugs into sensors, which plug into a brain, which plugs into motors, which move nature. Any computable equation or function can be made into hardware this way.

From now on, when you see an equation, also see the inputs, output, the program, and the connections.

- -, +, o, a, >, <, is, g, l, z are operators
- Not, n, d and i are functions
- <- is a data flow indicator (here from right to left)
- = is the transfer operator (it may be read as "becomes")
- ; is a comment delimiter

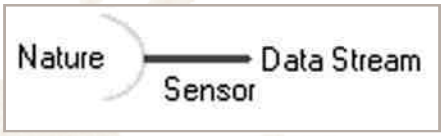
Sensors read nature and write data streams:

Sense -> Output

Definition: Sensor writes a data stream.

Nature -> O ; is the equation

Here is some pseudocode for a sensor:

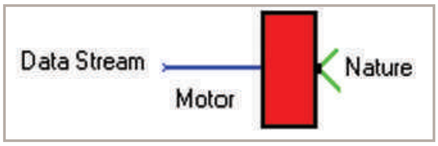



```
Sensor:
 Read a property of nature
 Convert it          ; Light intensity to number
 Write to O
 Go to Sensor:       ; Do this forever
```

Here, the motor reads a data stream and writes to nature:

Input -> Action

Definition: Motor reads a data stream.



I -> Nature ; is the equation

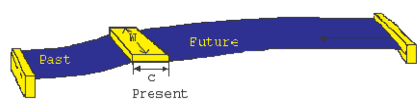
Here is some pseudocode for a motor:

```
Motor:
 Read I
 Convert it to an action    ; run CW, CCW
 Write it to nature
 Go to Motor:               ; Do this forever
```

Any sensor can connect to any motor with a data stream cable. Sensor -> Motor. The data stream cable can have any name. We say ThisMotor = ThatSensor. That means ThisMotor is pasted on the motor input I, and ThatSensor is pasted on the sensor output header O. Anywhere there is a header, a data stream socket can connect. Data streams carry information.

This month, you were introduced to Hal Algebra as a way to design neurons for robots. Neurons are simply functions that can be modeled by mathematics. I gave several examples of simple neurons and showed how they can be used to describe the actions between sensors, motors, and the robot's environment.

In a future article, we'll cover a few more functions and start combining them into HalTrees. Finally, we'll put all this knowledge to use by designing a brain for a simple microbe living in a pond.



ABOUT THE AUTHOR

You can learn more about Harold L. Reed's work at his website, **www.halbrain.com** and he can be reached at hlreed@halbrain.com

What Would You Trust A

by Jeannine Gailey

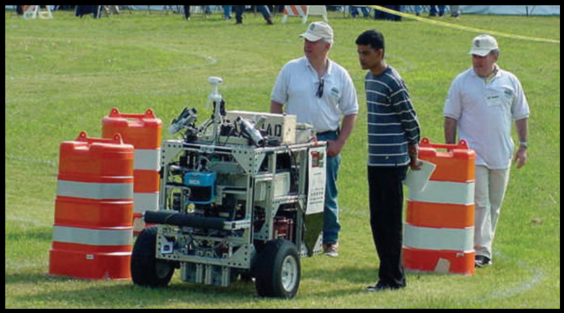
Dr. Ernest Hall builds robots that learn from their mistakes. Adapt or perish!

Robot To Do?

On any given Saturday this summer at the University of Cincinnati, you will find Dr. Ernest L. Hall, Director of the Robotics Center, in the robotics laboratory with a dozen or so students, eating pizza and comparing ideas for their robot, the Bearcat (named after University of Cincinnati's team mascot), which will be competing in the Intelligent Ground Vehicle Competition in 2004. The students are from graduate and undergraduate programs as diverse as mechanical, industrial and electrical engineering, computer science, and psychology. Dr. Hall, who recently won an Innovative Teaching award, has spent 20 years giving students the opportunity to apply the theory they learn in his classes by designing and building a robot that is capable of guiding itself through an obstacle course.

Dr. Hall is interested in robotics, but also interested in the practical application of engineering design, artificial intelligence theories, software and hardware programming, and plain old mechanical ability. And he wants to make that application fun. That is why students are willing to give up their free time to work in the lab building and programming a robot that can gather information about its surroundings, make decisions, and physically master a series of challenges. This isn't your average Radio Shack robot made for a quick derby battle, content to be driven by a person with a remote control. In many ways, it is a thinking machine.

Why Intelligent Robots?



You can see the potential for thousands of applications — robots that could navigate a street without running over pets or crashing into other objects could perform routine duties such as street cleaning or trash collection. Such robots could also perform risky blood work in a medical lab, or take the strain off overworked hospital staff by doing tasks like delivering meals to patients or collecting soiled laundry. What would you trust a robot to do? This is a key question, Dr. Hall points out, one that both defines and limits the goals of robotic researchers. If a robot is developed that could administer vaccinations, would people trust a robot to do that? But, if the robot could be trained to perform janitorial duties at a nuclear waste site, and this eliminated risk to human life, would people be more willing to trust it then? The practical advantage of robots that can learn is in allowing robots to take the place of humans in dangerous situations, which means having robots that could detect and avoid land mines, or collect hazardous materials at a Superfund site without contaminating safe areas.

Dr. Hall, who has written three books and hundreds of papers and articles on machine intelligence, knows that the idea of an intelligent robot may sound pie-in-the-sky. But he points to examples of intelligent robots that are already in the workforce — the robot lawn mower, robot vacuum cleaner, robot food delivery system and robot helpers for the elderly. Unmanned military ground, underwater, and aerial vehicles are currently beind developed at an accelerated pace as well.

What is Machine Intelligence?

Alan Turing is often thought of as one of the "fathers" of Artificial Intelligence, the science of creating intelligent computers. As early as 1947, he believed machine intelligence would be found in the ability to communicate with natural language. Some "bots" on the web are now savvy in the natural language department. In the 1970s, research into artificial intelligence moved towards creating machines that could respond to visual stimuli, and some scientists tried to replicate the data manipulation of the human brain, building machines with neural networks.

Dr. Hall defines machine intelligence as requiring two attributes. The first is the ability to react to sensory information. "We have been doing this for twenty years," he says. Examples of this today include AIBO, the robot dog from Sony that has the ability to respond to sound, touch, and visual stimuli. However, AIBO cannot learn. "The other, more challenging, aspect of machine intelligence is creating a computer brain that can learn from repetitive actions." With his students, Hall has been studying neural networks in robots — that is, an architecture in which computer processors are interconnected similarly to the way neurons connect in a human brain. This system allows the computer to learn by a process of trial and error. "We need to be more patient with our robots," Hall says. "Giving them time to learn may mean exposing them to not hundreds but thousands of iterations over time." More advanced ideas about neural networking have emerged recently - for instance, the ideas of the adaptive critic and creative learning.

Dr. David Casasent, a professor of electrical and computer engineering at Carnegie Mellon University, and also a researcher in the area of optical systems, has worked with Dr. Hall for over 20 years. "When we started the SPIE Intelligent Robotics and Computer Vision Conference, vision guided robotics was just a research idea. Now we have several of these ideas put into actual practice, such as the Sojourner that is on Mars, and many vision-guided robots in industry and defense."

Q/A With Dr. Hall

JG: What is this adaptive critic learning?

Dr. Hall: The adaptive critic is a form of reinforcement learning that was developed by Paul Werbos of the National Science Foundation (NSF). It uses a back-propagation algorithm of a neural network to distribute error through the network network and make the adjustments needed to learn a given goal. In robotics, it can be used, for example, to make a robot follow a precisely specified path.

JG: How would you define creative learning and how is this approach different from existing techiques in machine intelligence?

Dr. Hall: Creative learning chooses one of several goals - this

WANT TO KNOW MORE ABOUT Intelligent ROBOTS?

Web Sites of Interest:

www.robotics.uc.edu - The University of Cincinnati's Robotics web page
www.igvc.org/deploy - The Intelligent Ground Vehicle Competition web page
www.auvsi.org - The main sponsoring organization for the University of Cincinnati robot team
www.ai.mit.edu - MIT Artificial Intelligence Lab site
http://vasc.ri.cmu.edu - Carnegie Mellon's Robotics Institute's Vision and Autonomous Systems center
www.aaai.org/Pathfinder/index.html - A Web site of the American Association for Artificial Intelligence

is the creative part. Once a goal is selected, the adaptive critic can be used to let the robot achieve it. This approach has one higher level of control than the adaptive critic alone.

JG: Tell me a little bit about the robot that you are designing to test creative learning.
Dr. Hall: We have designed the hardware of the Bearcat Cub, a small modern version of our existing Bearcat robot. It has a hybrid power source that will generate electrical power from a small, quiet gas engine. It also uses Segway™ high traction wheels and gearboxes. It also has a web-based Galil™ motion controller and will be run from a Dell laptop. We are also designing creative control and learning software for it.

JG: How does the robot you are working on display decision-making abilities?
Dr. Hall: The robot's program employs decision making logic. It starts by following a line on the ground. If an obstacle is encountered, it must go around, and then return to line following. If the line disappears, it looks on the other side of the path for it.

JG: So, which type of creative learning or machine intelligence does the robot you take to the contest display? And what makes your robot different or more intelligent than, say, the robotic vacuum cleaner that's now commercially available?
Dr. Hall: The type of machine intelligence programmed into our robot for the contest is goal accomplishment with adaptation. That is, during the line following (autonomous challenge) part of the contest, the robot's goal is clear: go the longest distance in the shortest time. It is even given lines to follow. However, along the way there are obstacles to avoid, a hill to climb, a sand trap, an asphalt section where the lines change colors and portions where the lines become dashed and disappear. Adapting in real time to all these changing environmental conditions displays one form of machine intelligence. In the navigation part of the contest, the robot is given waypoints that mark locations on a map. However, it must first determine which waypoint to go to and still avoid obstacles along the way.

Finally, in the follow-the-leader part of the contest, the robot must follow a human driven vehicle at a given distance even when the leader vehicle turns, speeds up and slows down. Each of these adaptive behaviors show a little intelligence.

Certainly, the exploration into intelligent robots that University of Cincinnati's Dr. Hall and his team exemplify what is happening at other colleges in the United States, from MIT and CMU to the more far-flung reaches of Japan, Wales, and Finland. With increased interest and funding, and more everyday applications being solved, these programs will soon be the birth place of the next generation of decision making robots.

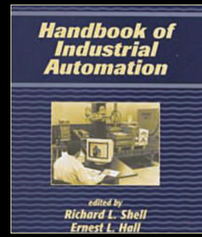
AUTHOR BIO

Jeannine Gailey, who has worked at Microsoft, IBM, and AT&T, is currently a consultant and writer whose book on XML Web Services is debuting this fall from Microsoft press. You can learn more about her work at **www.webbish6.com**, and she can be reached at writer@jeanninegailey.com.

TAKE A CLOSER LOOK ...

Check out these cool books to learn more about intelligent robots!

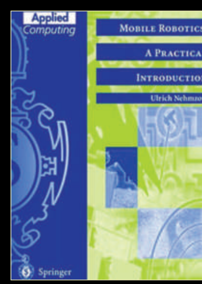
Hanbook of Industrial Automation
Edited by Richard L. Shell and Ernest L. Hall; Hall also wrote ***Computer Image Processing and Recognition***



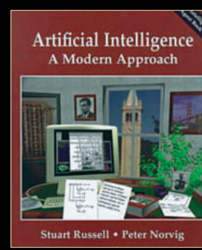
Behavior-Based Robotics (Intelligent Robotics and Autonomous Agents)
by Ronald C. Arkin

Mobile Robots: Inspiration to Implementation
by Joseph L. Jones and Anita M. Flynn

Mobile Robotics: A Practical Introduction
by Ulrich Nehmzow



Artificial Intelligence: Modern Approach
by Stuart J. Russell and Peter Norvig

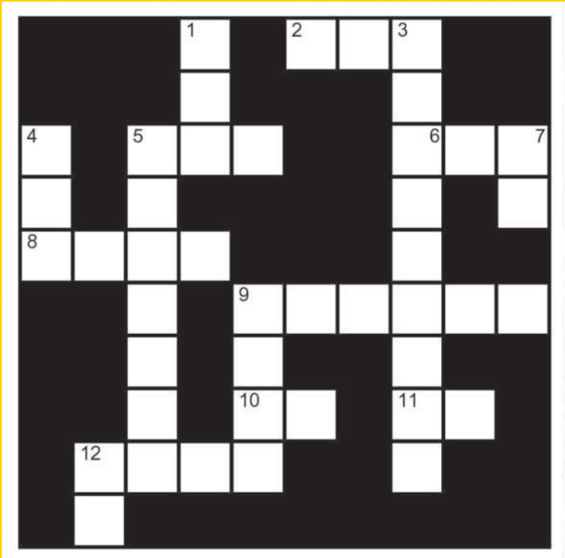


Atificial Intelligence and Mobile Robots: Case Studies of Successful Robot Systems
Edited by David Kortenkamp, R. Peter Bonasso, and Robin Murphy

Sensors for Mobile Robots: Theory and Application
by H.R. Everett

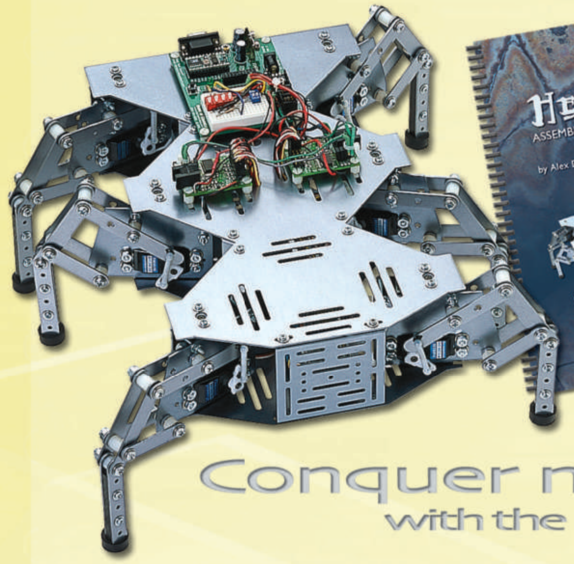
APPETIZER π

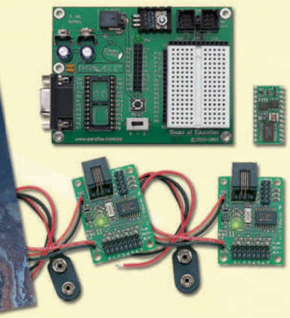
A numeric crossword! Do you really need a calculator?



Across		Down	
2.	Opamp	**1.**	Middle A
5.	Gold+zinc	**3.**	Fibonacci
6.	Right triangle	**4.**	$ for passing Go
8.	Sqrt(2)/2	**5.**	Seconds in a fortnight
9.	355/113	**7.**	Prime after 47
10.	Greek alphabet	**9.**	MIDI clock
11.	Human chromosomes	**12.**	2D pentominoes
12.	H-O-H bond angle		

HexCrawler





Conquer new terrain with the HexCrawler

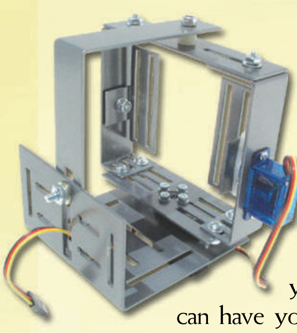
The HexCrawler kit contains all of the key hardware needed to build and program this customizable robot. A BASIC Stamp 2, Board of Education programming board and two Mini SSCII servo controllers determine movement. With 12 servos performing the gaits, the HexCrawler has a payload capacity of 7.5 lbs.

Every detail of assembly is covered in the manual along with sample programs to get you familiar with its high complexity. From there, you can add sensors and additional components to the 155 sq. inch frame for increased functionality. Once you have assembled and fine tuned your HexCrawler, it is then a platform with high potential for advancements utilizing the accessories shown here.

You will need to supply a few hand tools for assembly, some wires, a PC for programming, and a 7.2V battery pack.

HexCrawler Full Kit; #30063; $695.00
HexCrawler is available only from Parallax, Inc.

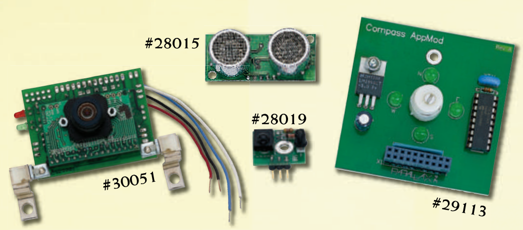
Accessories



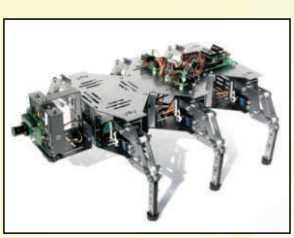
The Universal Sensor Scanning System was designed to overcome the limitations of "fixed" sensors on various robotics applications. With the addition of the fully adjustable S³ system to your robotic application, you can have your HexCrawler stay in one place while it senses the surrounding environment.

You can utilize any combination of ultrasonic sensors, rangefinders, infrared detectors and the CMUcam with the addition of the S³ system to the HexCrawler.

S³ (Sensor Scanning System) is available only from www.CrustCrawler.com for $109.00.



Pictured Clockwise: **Devantech SRF04 Range Finder, Compass AppMod, SSIR Detector, CMUcam**
Visit www.parallax.com for pricing and detailed information.



CMUcam and the S³ mounted onto the HexCrawler.

www.parallax.com

PARALLAX

To order, visit our website or call toll-free (in the U.S.) at 888-512-1024 (Monday-Friday, 7 a.m. - 5 p.m., PST).